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Local Convergence and Global Diversity: From Interpersonal to Social Influence

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Abstract

How can minority cultures resist assimilation into a global monolith in an increasingly "small world"? Paradoxically, Axelrod found that local convergence can actually preserve global diversity if cultural influence is combined with homophily, the principle that "likes attract." However, follow-up studies showed that this diversity collapses under random cultural perturbation. The authors discovered a new source of this fragility—the assumption in Axelrod's model that cultural influence is *interpersonal* (dyadic). The authors replicated previous models but with the more empirically plausible assumption that influence is *social*—people can be simultaneously influenced by several network neighbors. Computational experiments show that cultural diversity then becomes much more robust than in Axelrod's original model or in published variations that included either social influence or homophily but not both. The authors conclude that global diversity may be sustained not by cultural experimentation and innovation but by the ability of cultural groups to discourage those activities.

Keywords

social influence, social networks, cultural diversity, homophily, cultural drift, agent-based models

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Cultural diversity is both persistent and precarious. Mark (1998a, 2003) showed how preferences for a particular music style cluster among those who are similar in age or education. Glaeser and Ward (2006) analyzed the regional distribution of political and social views in the United States and concluded that "the extent and permanence of cultural divisions across space is one of America's most remarkable features" (119–20). At the same time, people in different regions of the world are increasingly exposed to global influences from mass media, Internet communication, and interregional migration. English is rapidly becoming Earth's *lingua franca*, and Western music and fashions appear even in remote villages around the globe. While some authors emphasize the pervasiveness of cultural differences, others expect the emergence of a universal monoculture (cf. Greig 2002). This is grounded not only in empirical observation of recent trends (Friedman 2005) but also in formal theoretical models of social influence. Building on French (1956), Abelson (1964), and Harary (1959) developed formal models that describe social influence as a process in which individuals move toward the weighted average of the opinions of others with whom they interact. They proved that convergence to global consensus was inevitable in a connected (or what Abelson called a "compact") network—in which there are no components that are entirely cut off from outside influences (Abelson 1964; Harary 1959). Obviously, diversity could be easily maintained in a world where everyone lived on a small island with identical neighbors, isolated from outside influence. But how is diversity possible in a world in which people cannot avoid exposure to those who are different?

The problem stems from one of the fundamental principles of human interaction—social influence—the tendency to alter one's opinions, attitudes, beliefs, customs, or other cultural traits to more closely resemble those of influential others (Festinger, Schachter, and Back 1950; cf. Axelrod [1997] for an overview). Abelson and Harary's models predict cultural homogeneity as the inevitable outcome of processes by which individuals influence their network neighbors in response to the influences they receive. Later modifications (Friedkin and Johnsen 1990, 1999) took into account that actors may retain some residue of their original traits, no matter how great the influence of others. However, these models still imply that influence greatly reduces differences, typically leading to a very low degree of diversity in connected networks (cf. Friedkin 2001).

This was the prevailing view among formal theories of cultural dissemination until about a decade ago. Building on previous work by Carley (1991) and by Nowak, Szamrej, and Latané (1990), Axelrod (1997; see also Mark 1998b) proposed an agent-based model with two innovations. First, he assumed opinion scales that are discrete, while French, Abelson, and Harary studied dynamics on continuous opinions. Second, he combined cultural influence with homophily, the principle that "likes attract" (Lazarsfeld and Merton 1954; Byrne 1969; McPherson, Smith-Lovin, and Cook 2001). Like earlier formal models, Axelrod's assumed agents are connected in a network. However, Axelrod added that the likelihood of interaction between two neighbors could vary over time, depending on their similarity. More

specifically, if two agents are too dissimilar, no social influence occurs between them, neither positive (assimilation) nor negative (differentiation). Homophily generates a self-reinforcing dynamic in which similarity strengthens influence and influence leads to greater similarity. This might appear to merely strengthen the tendency toward global convergence generated by earlier models without homophily. However, Axelrod's computational studies showed how local convergence can trap a population in a globally diverse equilibrium in which influence is no longer possible between neighboring cultural regions that have insufficient similarity for interaction (and hence influence) to take place across the cultural boundary. Once the members of two cultural regions have become too dissimilar to influence one another, their cultures[1] evolve along divergent paths, akin to biological speciation when sexual organisms with a common ancestor differentiate beyond a critical threshold for reproduction.[2] This model accounts for both tendencies evident in cultural evolution—the relentless assimilation of cultural minorities, and the inability for this process to end in monoculture.

Axelrod's discovery of how local convergence can explain global diversity inspired numerous follow-up studies addressing issues ranging from the influence of mass media (Shibanai, Yasuno, and Ishiguro 2001; González-Avella et al. 2007) to effects on cultural diversity of globalization (Greig 2002), geographical boundaries (Parisi, Cecconi, and Natale 2003), and dynamic networks (Centola et al. 2007). Other studies used ''bounded confidence'' models that combined homophily with continuous opinion scales (Deffuant et al. 2000; Hegselmann and Krause 2002). The bounded confidence models showed that global diversity does not depend on the assumption that opinions are discrete, as long as influence can only occur between individuals who are sufficiently similar. Thus, while Axelrod introduced two innovations—discrete opinions and homophily—these subsequent studies showed that the latter is sufficient for local convergence to preserve global diversity.

However, recent work by Klemm et al. (2003a, 2003b; cf. De Sanctis and Galla 2009) identifies a serious problem in Axelrod's results. Starting from the original model, they relaxed Axelrod's assumption that cultural traits are entirely determined by influence from neighbors and allowed instead a small probability of random perturbation of cultural traits. This small and highly plausible change made cultural diversity far more fragile than Axelrod had suggested. Cultural perturbation increases local heterogeneity by allowing agents to spontaneously deviate from their neighbors by altering one of their cultural traits. Paradoxically, a small probability of perturbation promotes not diversity but global convergence. Random cultural perturbations can generate cultural overlap between otherwise dissimilar neighbors, thereby breaching their cultural boundary. The overlap makes interaction possible, and once interaction occurs, influence reduces remaining differences, increasing the probability of future interaction. Thus, formerly dissimilar neighbors become increasingly similar until no differences remain and a new cultural boundary forms around a larger

region. Eventually this boundary too will be breached by a perturbation that creates a common trait between otherwise dissimilar neighbors, and so on, until no differences remain.

Results reported by Klemm et al. (2003a; hereafter, KETS) also suggest a second mechanism by which perturbation undermines cultural diversity. If the rate of perturbation is sufficiently high, perturbation is introduced faster than influence can reduce it, leading to cultural turbulence that precludes the formation of stable cultural regions. Following Centola et al. (2007, 918), we characterize this condition as "anomie" to indicate the failure of social pressure to maintain conformity to local cultural norms. Anomie should not be confused with cultural diversity. The latter requires cultural convergence within internally homogenous regions that differ from one another sufficiently that they maintain their distinctiveness over time. Anomie means distinct regions cannot coalesce, due to the evanescence of individuals who differentiate themselves from one another more than they are attracted to one another.

These two mechanisms attack diversity from two sides. If the noise rate is sufficiently low, perturbations breach the boundaries between cultural regions, promoting assimilation. If the rate is sufficiently high, perturbations preclude local convergence. Thus, cultural diversity is only viable within a narrow window of perturbation rates that closes asymptotically as population size increases.

This extreme fragility of cultural diversity in the Axelrod model has prompted the search for mechanisms that reconcile perturbations and robust cultural diversity. One study extended homophily to the evolution of network structure (Centola et al. 2007; hereafter, CGES), while another eliminated homophily entirely (Parisi, Cecconi, and Natale 2003; hereafter, PCN).

The present research continues this line of inquiry. Our principal contribution is the discovery of the source of the fragility in Axelrod's model: that influence is interpersonal rather than social. With one notable exception (PCN), the assumption that influence is interpersonal has been inherited uncritically by follow-up studies, without anyone noticing the implications for the robustness of cultural diversity. Interpersonal influence is dyadic while social influence is multilateral. Dyadic influence is analogous to the spread of disease from one infected person to another. This allows a local carrier of an alien culture to infect one neighbor at a time, regardless of the number of other neighbors who might easily overwhelm the deviant influence if they were permitted to exert countervailing influence. By allowing only dyadic influence, resistance to infection is rendered futile. By the time one of the uninfected neighbors has their turn to interact, it is too late: their neighbor is already infected and is as likely to spread the infection as to be cleansed.

In sharp contrast, a previous generation of models, dating back to French (1956), assumed that influence is *social*. Social influence differs from disease in that the process of social contagion is multilateral: agents respond to the distribution of traits across all their neighbors, not just to the traits of the neighbor with whom they currently interact (Nowak et al. 1990). This prevents an infected agent from luring its neighbors one at a time. Otherwise, the local majority culture will prevail. The

"power of the group" (Festinger, Schachter, and Back 1950) to prevent members from becoming deviant finds empirical support in research on "majority influence" (cf. Forsyth [1990, 148] for an overview; see also Latané and Wolf 1981).

To preview our results, we show that social influence increases the likelihood that cultural perturbation will be reversed before it can breach the boundary between otherwise dissimilar neighbors. This also means that high perturbation is less likely to produce anomic cultural turbulence. Thus, social influence tempers both cultural drift into monoculture via dyadic transmission and degeneration into cultural anomie via perturbation rates that exceed the rate at which influence can build stable cultural regions.

Our primary interest focuses on Axelrod's assumption that influence is interpersonal, but he employed a second hitherto unexplored assumption that turns out to also be highly consequential, both for the original as well as follow-up models. This is the assumption that perceptions of similarity are error free; hence, two maximally dissimilar neighbors can never influence one another accidentally. Yet human perception is rarely perfect; there is always the possibility of "selection error," such that we see more or less similarity than actually exists. Like cultural perturbation, selection error can cause interaction to occur across the boundary between dissimilar cultural regions that would otherwise be disconnected, leading to an eventual merger and a decline of diversity. However, unlike cultural perturbation, which alters the similarity to every neighbor, selection error affects only the single neighbor whose perception is mistaken. Put differently, cultural perturbation is multilateral (like social influence), while selection error is dyadic (like interpersonal influence). In order to compare social and interpersonal influence, it is therefore useful to incorporate both cultural perturbation and selection error as two sources of noise.

We use computational experiments to show how the combination of homophily and social influence generates cultural diversity that is highly robust to both cultural perturbation and selection error under conditions in which diversity collapses in three previous extensions of the original Axelrod model: the cultural perturbation model of KETS, and two alternative specifications that extend homophily (CGES) and eliminate it (PCN).

An Extended Model of Influence and Homophily

In Axelrod's original model, as well as in most of the follow-up studies including KETS and CGES, a population of N agents is distributed over a regular bounded (non-toroidal) lattice, where each cell is typically occupied by a single agent who can interact with four adjacent neighbors in a Von Neuman neighborhood (those to the N, S, E, and W).[3] Axelrod (1997) also experimented with the size of the neighborhood. He noted that a very small neighborhood helps preserve diversity by making it relatively likely for an agent to be entirely dissimilar to all its neighbors. Larger neighborhoods are not only more empirically plausible (Fischer 1982; Fischer and Shavit 1995) but are also a more conservative test of the preservation
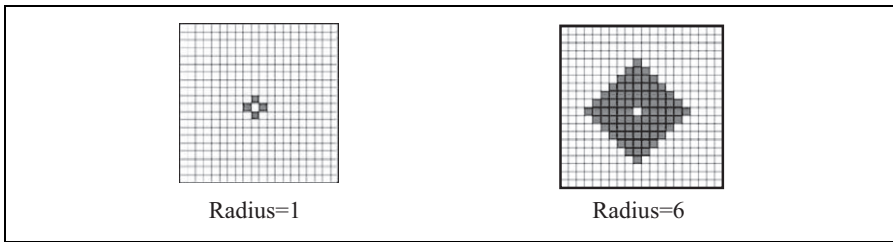
Radius=1   Radius=6

Figure 1. Cells belonging to the neighborhood of the agent in the center, with radii 1 and 6

of cultural diversity. We therefore incremented the radius of the Von Neumann neighborhood from 1 to 6, which increases the maximal number of neighbors for each agent from 4 to 84, as illustrated in Figure 1.

Axelrod defined the cultural profile for an agent as a vector of F features. On any feature f, an agent has a trait q represented by an integer value in the range $q = \{0, \ldots, Q-1\}$, where Q is the number of possible traits on that feature. Formally, the cultural profile C of agent i is

$$C_i = (q_{i1}, q_{i2}, \ldots, q_{iF}), \quad q_{ix} \in \{0, 1, \ldots, Q-1\} \subset N_0 \tag{1}$$

In all experiments, we define an F by Q cultural space based on the parameters that Axelrod found to be conducive to high levels of diversity and that he used for many of the experiments he reported: $F = 5$ cultural features with $Q = 15$ traits per feature. We also followed Axelrod, KETS, and others in initializing a population of agents with a random cultural profile in which each feature is assigned a trait q from a uniform distribution. The sequence of events in each iteration of the model is as follows:

1. In every discrete time step t, an agent i is randomly chosen from the population, and i's cultural profile may then be updated through possible interaction with a randomly chosen neighbor j.
2. If interaction is based on homophily, i decides whether to interact with j with a probability p_{ij} that is equal to the proportion of all F features on which i and j have identical traits, where i and j are identical on f if $q_{if} = q_{jf}$. If interaction is not based on homophily, $p_{ij} = 1$, regardless of cultural similarity.
3. With probability r', selection error occurs. That is, if by rules 1 and 2, agent i has decided to interact with j, the decision will be reversed and the interaction will not take place. Correspondingly, if i has decided not to interact with j, selection error will change this decision into interaction.
4. If influence is social, steps 2 and 3 are repeated in turn for each of the other neighbors of i. This creates a subset $\mathbf{S}$ of i's neighbors designated as influential. If influence is interpersonal, step 2 occurs only once; hence, $\mathbf{S}$ contains at most one member (namely, j) but may be empty. If influence is social, $\mathbf{S}$ contains at most all neighbors of i but may be empty.

5. If **S** is not empty, i randomly chooses a feature f from the set of features on which change is possible. That is, on feature f there is at least one trait different from i's current trait that is shared by at least as many members as is i's current trait. Agent i observes for every trait q on f the number of "votes" that q receives from the members of **S**. Then, the new trait q^* that i adopts on f is randomly chosen from the set of traits with a maximal number of votes vfq for trait q of feature f (modal traits), or, traits m that satisfy $\forall m' : v_{fm} \geq v_{fm'}$, where $v_{fx} = \|\{k \in \mathbf{S} | q_{kf} = x\}\|$ and $0 \leq m \leq Q - 1$. There is one exception to this rule: if more than one trait is modal in **S**, and the set of modal traits includes i's present trait, preference is given to the trait already adopted by i (i.e., i only abandons a trait in favor of one with greater support among i's influential neighbors).

6. Following KETS (2003a, 2003b), one of i's features is randomly chosen and a random trait on this feature is then perturbed with probability r to a new value randomly chosen over the interval $\{0, \ldots, Q - 1\}$.

Step 6 implements the one change that KETS made to Axelrod's model, adding cultural perturbation with a probability r. Steps 3 and 4 relax two additional assumptions in the Axelrod model. In Step 3, we implemented selection error as a probability r' that a dissimilar neighbor will be misclassified as sufficiently similar to be included in **S**, or a similar neighbor as dissimilar. Step 4 contains a switch that controls whether an agent can be influenced by more than one neighbor at a time. When the switch selects interpersonal influence, a randomly chosen neighbor j is the sole candidate member of **S**, and when social influence is selected, all of i's neighbors are candidates. With $r = r' = 0$ and interpersonal influence plus homophily, the model is identical to the original Axelrod model. Introducing $r > 0$ (but leaving $r' = 0$), the model is identical to that used by KETS. Allowing agents to change neighbors ("network homophily") as well as interaction partners (the "interaction homophily" assumed by Axelrod), the model is identical to CGES.[4] Turning off homophily (in step 2) and activating social influence (in step 4) implements the mechanism assumed by PCN. Turning homophily back on implements a new model that combines homophily with social influence, which we show provides the most persuasive explanation for the persistence of high levels of cultural diversity, especially in large populations. Table 1 gives an overview of the models that can be generated as special cases of our general mechanism. We compare within one framework the models of KETS, CGES, PCN, and our new model of social influence.

The population dynamics were generated by iterating the sequence of six steps a finite number of times. Our outcome measure is the level of cultural diversity on the last iteration, averaged over fifty independent realizations (which proved to be sufficient, given the low variance in outcomes across realizations). Axelrod measured diversity as the number of cultural regions, while KETS and CGES used the size of the largest cultural region (normalized for comparison across population sizes as $S_{\max}/N$). We used both these measures. Axelrod defines a cultural region as a

Table 1. Overview of models generated by rules 1–6 and network-homophily rule (explained in the online appendix)

Influence mechanism	Homophily	Perturbation ($r > 0$)	Network homophily	Model
Interpersonal	Yes	No	No	Axelrod
Interpersonal	Yes	Yes	No	KETS
Interpersonal	Yes	Yes	Yes	CGES
Social	No	Yes	No	PCN
Social	Yes	Yes	No	Social influence + homophily

Note. KETS = Klemm et al. (2003a); CGES = Centrola et al. (2007); PCN = Parisi, Cecconi, and Natale (2003).

maximal set of directly or indirectly connected agents with identical culture. Using this measure, the level of diversity ranges from a low of $S_{max}/N = 1$ when $S_{max} = N$ (all agents are members of a single region) to a high that approaches $S_{max}/N = 0$ when $S_{max} = 1$ (every agent differs from all its immediate neighbors). In a stochastic process, neither of these extreme forms of monoculture and anomie is likely to persist. A more conservative benchmark adds a small margin of error to the regions of monoculture and anomie. Accordingly, we classify an outcome as monoculture if on average 99 percent or more of the population belongs to the same cultural region, and we deem a population in a state of anomie if cultural regions contain fewer than three members. The need for at least three members follows from Simmel's (1950) classic notion that social relations embedded in a triad are essential for social consensus. While triads in which all members can influence one another would be impossible in a Von Neuman neighborhood with radius 1, our assumption of an influence radius of 6 allows the formation of such triads. Thus, if the size of regions, averaged across all regions in a population and across the independent realizations of the experiment, is smaller than three ($\overline{S_{max}} < 3$), we define the outcome as anomie.[5]

Between anomie and monoculture, diversity declines with the size of the largest region and increases with the number of regions. We evaluated these intermediate cases using two additional measures: the proportion of realizations in which monoculture or anomie obtain, and the presence of a dominant cultural region, defined as a region containing a majority of the population ($S_{max}/N \geq 0.5$).

We set the number of iterations at a value large enough for the population dynamics to approach stochastic stability in most conditions. With zero noise, equilibrium is guaranteed and easily tested (all pairs of agents are either identical or dissimilar to one another on all features; hence, no further change is possible and iteration can be terminated). With nonzero noise, the population converges toward a stochastically stable state. For most of the conditions, 10^5 iterations per agent was more than sufficient; in few cases with very low perturbation rates, we needed 10^6 or more iterations per agent to approach a stochastically stable outcome.

Previous studies show that cultural diversity is more vulnerable in large populations, either to monoculture (if noise is assumed away, as in Axelrod) or anomie (if noise is allowed, as in KETS). We therefore varied population size, starting with $N = 100$ agents on a 10×10 lattice. We then increased N in two steps, each larger by roughly a factor 10 ($N = 1024$ on a 32×32 lattice and $N = 10,000$ on a 100×100 lattice). We also increased the size of neighborhoods from 4 to 84 and included selection error as well as cultural perturbation ($r = r' > 0$), as a more conservative test of the robustness of diversity.

Results

We began by replicating Axelrod's results for the absence of noise ($r = r' = 0$), using his standard scenario of $F = 5$, $Q = 15$ and a small radius of interaction (radius = 1), with three different population sizes. Our results confirmed that in the absence of noise, global diversity can be sustained in equilibrium in relatively small groups. For $N = 10 \times 10$, the average size of the largest cultural region in equilibrium is $S_{max}/N = 0.49$, with an average of about 20.7 distinct cultural regions, based on fifty independent realizations. We also replicated Axelrod's finding (1997, 214) that cultural diversity collapses even without noise, if population size exceeds a critical level. For $N = 32 \times 32$, the equilibrium outcome was close to monoculture ($S_{max}/N \cong 0.98$), and we obtained nearly perfect monoculture at $N = 100 \times 100$.

We now turn our attention to the collapse of diversity, even in small populations, in the presence of noise. We report results of three computational experiments that investigate the conditions in which local convergence sustains global diversity as we vary the size of the population and the level of noise. Experiment 1 demonstrates the fragility of diversity in the original Axelrod model based on interpersonal influence, as the rate of noise increases for three population sizes. We then examine two extensions of the Axelrod model that are thought to sustain diversity in the presence of noise—the network homophily model of CGES and the PCN model of social influence without homophily (experiment 2). We show that high levels of diversity are only sustained if the population is small (CGES) or the noise rate is small (PCN). Experiment 3 demonstrates the robustness of diversity in a ceteris paribus replication of Experiment 1 except that we replaced interpersonal with social influence.

Experiment 1: The Collapse of Diversity in the Axelrod Model

KETS demonstrated how cultural diversity collapses in the Axelrod model under small amounts of noise. They also show how diversity is restored if the level of noise exceeds a critical value. To begin, we repeated KETS analysis of the effects of noise using Axelrod's standard scenario, increasing the rate of noise exponentially in six steps, from 10^{-6} to 10^{-1}, but retaining their assumptions of the absence of selection error and a small neighborhood (radius = 1). Consistent with KETS, we found that a slight increase of the noise level to $r = 10^{-6}$ ($r' = 0$) entailed the collapse of diversity

even for the small population size for which it could be sustained without noise. For $N = 10 \times 10$, the size of the largest region increased from $S_{max}/N = 0.49$ with no noise to $S_{max}/N = 0.995$ with noise. Perfect monoculture obtained with or without this small perturbation for the larger population sizes. Our results also showed how using an identical model and increasing the rate of noise exponentially in six steps, from $r = 10^{-6}$ to $r = 10^{-1}$ resulted in the gradual shift from monoculture to anomie that KETS reported (further results are reported in online appendix A1).

We then increased neighborhood size to 84 (radius = 6) and introduced selection error ($r = r'$). The combination of cultural perturbation and selection error is a more conservative test of the robustness of diversity to noise. That is, if diversity can be sustained with both sources of noise, it can be sustained with either, but the converse is not true. Thus, a demonstration of diversity under perturbation that assumes away selection error remains inconclusive. We therefore simplified the presentation of results by including only the condition in which noise involved both sources. (More detailed comparisons of perturbation and selection error are included in the online appendices A1 and A2.) Although these changes constrained the viability of cultural diversity (see online appendix A1 for details), we nevertheless found that the qualitative results of KETS were highly robust over these parameter variations, as illustrated in Figure 2, which is nearly identical to their Figure 4 (Klemm et al. 2003a, 9). Figure 2 shows how the level of noise and the size of the population affect the size of the largest cultural region that is able to form within a finite number of iterations.

Figure 2 reveals a narrow window in the rate of noise within which cultural diversity can be sustained. With very low noise, we get monoculture, but too much noise disrupts local convergence by introducing random variation faster than influence can restore homogeneity. This leads to a condition CGES characterize as "anomie." More precisely, for all three population sizes, initial diversity collapses into monoculture ($S_{max}/N \sim 1$) when the noise rate is extremely low ($r = 10^{-6}$). Moreover, for all three population sizes, cultural regions are unable to form ($S_{max}/N \sim 0$) if the noise rate is sufficiently high, due to the breakdown of local convergence. In between, there is a small window of noise rates that are high enough to sustain global diversity but not so high that they preclude local convergence. The width of this window declines as population size increases. For $N = 100$, we find monoculture at or below $r = r' = 10^{-4}$ (or 0.0001) and anomie at or above $r = r' = 10^{-2}$ (or 0.01). That leaves a window of slightly less than .01. For $N = 1024$, the window shrinks to at most .001 and for $N = 10{,}000$, the window all but disappears. We observe monoculture ($S_{max}/N \approx 0.9999$) if noise is at or below 10^{-6} and we obtain anomie if the noise rate is 10^{-4} or higher, with regions containing on average not more than 1.24 members at $r = r' = 10^{-4}$. Interestingly, results for the absence of noise show that the larger interaction radius eliminated the qualitative difference between zero noise and a small noise rate. At $r = r' = 0$, we found monoculture in equilibrium for all three population sizes (average $S_{max}/N > 0.99$, based on ten independent realizations).
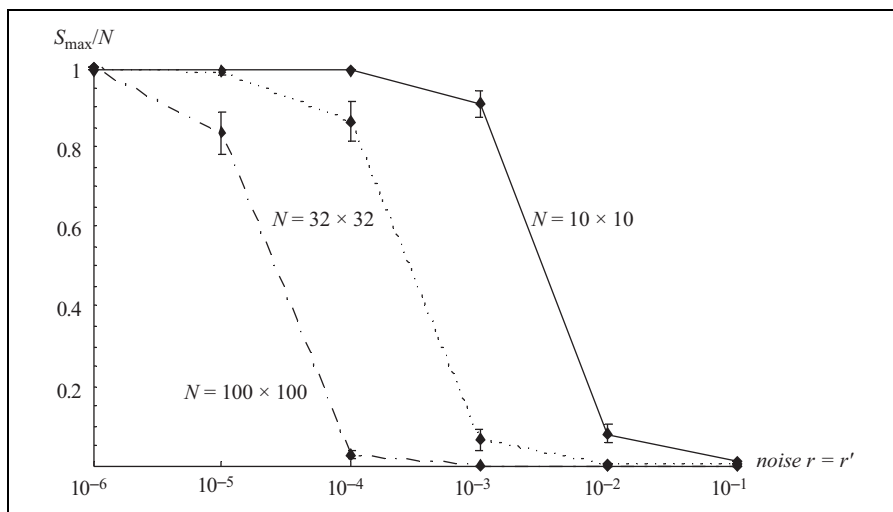
Figure 2. Homophily with interpersonal influence.
Note. Effect of the rate of noise ($r = r'$) on the normalized size of the largest region (S_{max}/N) in the final iteration, for three different population sizes ($F = 5$, $Q = 15$, radius $= 6$). Averages of final state over 50 realizations with 1,000,000 iterations per agent for $10^{-6} = r = r'$ and 100,000 iterations per agent otherwise. Error bars indicate 95% confidence intervals.

To sum up, experiment 1 confirms and extends the limitations reported by Axelrod and KETS. Even in the absence of noise, local convergence can sustain global diversity only in very small populations with very small neighborhoods. And in a world with cultural perturbation and selection error, diversity is sustained only within a narrow window of noise levels. With too little noise, Axelrod's original model implies inexorable cultural drift into monoculture. With too much noise, the outcome is anomie. In a nondeterministic world, cultural diversity is a highly improbable outcome of the Axelrod model unless the noise level is precisely engineered to remain within a vanishingly small window as the population size increases. It is difficult to imagine a population that would be blessed with a noise rate that fell within such a narrow window without invocation of an intelligent designer.

Experiment 2: Social Influence without Homophily

We now turn to two alternative specifications of the Axelrod model that have been shown to improve the robustness of diversity. CGES introduced network homophily, and PCN eliminated homophily while replacing interpersonal with social influence.

Following KETS, experiment 1 allowed cultural perturbations to create bridges across cultural boundaries. CGES precluded those bridges by completely removing the tie between dissimilar neighbors and replacing it with a random tie.

Otherwise, their model of network homophily retained KETS assumptions of a small neighborhood (radius = 1) and no selection error ($r' = 0$). For these conditions, we exactly replicated their results: network homophily prevented cultural drift into monoculture. But when we increased neighborhood size (radius = 6) and added selection error ($r = r'$), the largest cultural regions assimilated nearly the entire population, and the window of noise rates within which both monoculture and anomie can be avoided remained nearly as small as in the original Axelrod model. (More detailed results are reported in the online appendix.)

Another extension of the Axelrod model eliminated homophily. PCN showed that diversity can tolerate cultural perturbation if influence is social rather than interpersonal, even when interaction does not depend on similarity. Models of social influence date back to French, Abelson, and others who assumed that influence is multilateral rather than dyadic. Multilateral influence from all neighbors greatly reduces susceptibility to deviant influences. With more than one influential neighbor, it is impossible for a cultural deviant to induce a neighbor to adopt a perturbation that is an outlier within the distribution of traits over all influential neighbors. The only way for a cultural deviation to spread is for the deviant to be the only neighbor included in an agent's set of influential neighbors. Thus, social influence implies that deviations from a local norm are more likely to spread from i to a neighbor j the more traits that i and j have in common and the less that i has in common with other neighbors. In contrast, interpersonal influence implies that perturbations are more likely to spread from i to a neighbor j the more traits that i and j have in common, regardless of similarity with the other nonadopting neighbors.

PCN showed that diversity can be sustained even in the absence of homophily, as long as influence is assumed to be social rather than interpersonal. However, their experiments did not test the robustness of diversity to selection error and to larger populations and neighborhoods. Experiment 2 provides that test. The experiment is identical to experiment 1, except for two changes: influence is social rather than interpersonal and interaction does not depend on similarity. Rather than deciding with probability p_{ij} to interact with j, i includes every neighbor j in the set of neighbors with whom to interact (see step 4 in the model enumerated above). In step 3, selection error reverses this decision with probability r', exactly as implemented with interpersonal influence. Thus, the probability for inclusion in the influence set is $1 - r'$ for each of i's neighbors. Agent i then selects the modal trait of this set on a randomly chosen feature. Thus, if the set contains only j, social influence reduces to interpersonal. We turned off homophily by assuming $p_{ij} = 1$, regardless of the proportion of features on which i and j have identical traits (see step 2 above).

Figure 3 reports the effect of the level of noise ($r = r'$) on the normalized size of the largest cultural region at the end of the simulation runs, averaged across fifty realizations per condition. Figure 3 shows that, in the absence of homophily, social influence can preclude cultural drift into monoculture at low levels of noise, except for the smallest population size that we inspected ($N = 10 \times 10$). For $N = 1024$, a dominant culture emerges when the level of noise is at least 10^{-5} and for $N = 10,000$, if the
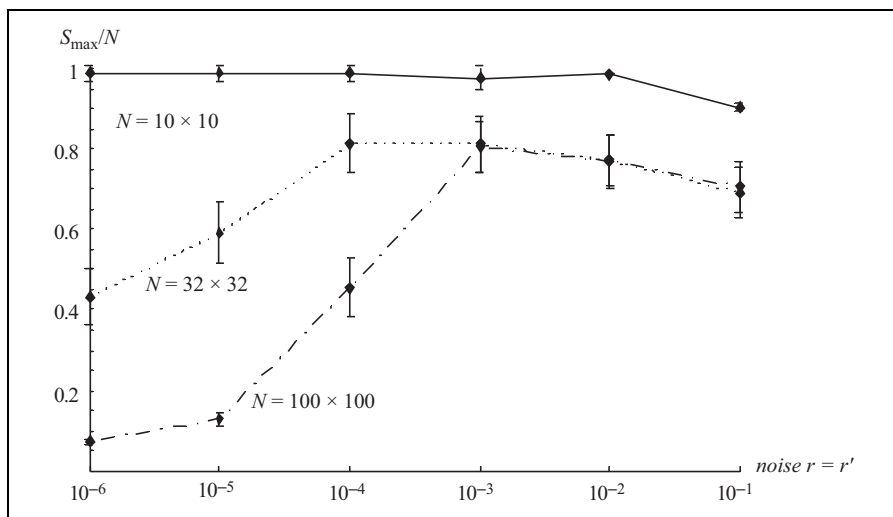
Figure 3. Social influence model without homophily.
Note. Effect of the level of noise on normalized size of the largest region (S_{max}/N) in the final iteration, for three different grid sizes ($F = 5$, $Q = 15$, radius $= 6$, $r = r'$). Averages of final state across 50 realizations with 1,000,000 iterations per agent for $10^{-6} = r = r'$ and 100,000 iterations per agent otherwise. Error bars indicate 95% confidence intervals.

noise rate is at least 10^{-3}. At $r = r' = 10^{-4}$ diversity is low, with a dominant culture encompassing on average a fraction of .81 of the population. In this condition, monoculture obtained in about two third of the realizations. From this peak level, the size of the largest region then slowly declines as the noise level increases further.

At the lowest noise rate ($r = r' = 10^{-6}$), the normalized size of the largest region is about .43 for $N = 1024$ and only about .07 for $N = 10,000$, in striking contrast to the monoculture that obtained with all three population sizes in experiment 1 (in which interaction was homophilous and influence was interpersonal rather than social).

Experiment 2 also shows that social influence without homophily precludes cultural anomie at noise levels where anomie obtained in Experiment 1. The smallest average size of the largest cultural region in any of the conditions inspected in experiment 2 was about .072 for $N = 10,000$ and $r = r' = 10^{-6}$. On average, a cultural region consists of about eighty-five agents in that condition, indicating a degree of local convergence that is well above the anomic levels observed with interpersonal influence and homophily in experiment 1, where on average regions were as small as 1.00006 agents (for $N = 10,000$ and $r = r' = 10^{-1}$).

There is yet another striking change when influence is social and interaction does not depend on similarity. A comparison with the results of the previous experiments
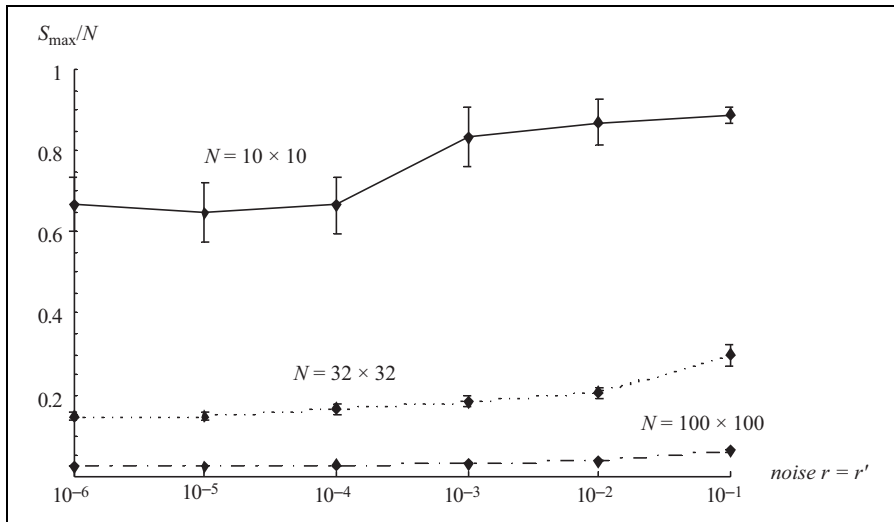
Figure 4. Social influence model with homophily.
Note. Effect of the level of noise on normalized size of the largest region (S_{max}/N) in the final iteration, for three different grid sizes ($F = 5$, $Q = 15$, radius $= 6$, $r = r'$). Averages of final state across 50 realizations with 1,000,000 iterations per agent for $10^{-6} = r = r'$ and 100,000 iterations per agent otherwise. Error bars indicate 95% confidence intervals.

reveals an apparent reversal in the qualitative effect of the noise rate. Consistent with previous work (Klemm et al. 2003a, 2003b; Centola et al. 2007), experiment 1 revealed a sharp transition from monoculture to cultural anomie when noise rates exceeded a critical value. However, with social influence and without homophily, the size of the largest region increases with the level of noise up to 10^{-4} (for $N = 1,024$) or 10^{-3} (or $N = 10,000$) and then declines. This non-monotonicity is evident in Figure 3 for the larger population sizes. Social influence makes it far more likely that a cultural perturbation will be reversed before it can spread, compared to interpersonal influence. A quick reversal is equivalent to the perturbation having never occurred. Thus, compared to interpersonal influence, social influence increases the amount of perturbation required to have an equal likelihood of creating a bridge between otherwise dissimilar neighbors. The larger the neighborhood, the higher the probability that perturbations will be reversed, given the disparity between the influence of the deviant compared to all other neighbors. With eighty-three neighbors competing for influence against one, a given noise rate with social influence is equivalent, in terms of the bridging effect of perturbation, to a rate that is many orders of magnitude smaller when influence is interpersonal. In sum, whether influence is interpersonal or social, the effect of noise on diversity is non-monotonic, initially decreasing diversity by creating bridges across cultural boundaries but then increasing diversity by introducing cultural perturbations faster than influence can

reverse them. The essential difference is that reversals are exponentially far more likely when influence is social, and increasingly so as neighborhood size increases.

Finally, the results in Figure 3 also address a second paradox in the original Axelrod model: the prediction that diversity is stable only for very small populations with less than a few thousand people. Everywhere else, the original model predicts monoculture. This is a discouraging result because it is more plausible to expect monoculture in small isolated groups (such as intentional communities or remote tribal villages) and diversity in large societies, a discrepancy that concerned Axelrod as well (1997, 220). The collapse of diversity in large populations, even in the absence of noise, is driven by a lack of resistance to deviants. As Axelrod showed, the number of influence rounds needed until cultures have stabilized increases exponentially in the size of the population. But "the more time it takes for a territory to settle down, the more chance there is that . . . regional boundaries will be dissolved" (1997, 219) if cultural changes increase the similarity of previously dissimilar neighbors. However, social influence greatly increases the robustness of regional boundaries. Effective social influence across a boundary can only occur if a sufficient number of neighbors from the other side become similar to a focal agent. It takes much longer before this can happen than in the model with interpersonal influence. But in the meantime there is also ongoing pressure toward local convergence. Social influence imposes a stronger pressure to conform to local norms relative to the pressure to reconnect to outside neighbors, compared with interpersonal influence. As a consequence, diversity is much more robust when influence is social rather than interpersonal, even in a large population. This robustness entails a positive effect of group size on diversity, because in a large population, there are more cultural regions that form and stabilize simultaneously than in a smaller population.

In sum, even without homophily, a model with social influence not only explains the resistance of diversity to the effects of noise, it also addresses Axelrod's paradox of group size: diversity increases with population size, particularly at relatively low noise levels, a result that is more in line with empirical intuition than what Axelrod found with a model that assumed influence was interpersonal.

Experiment 3: Social Influence and Homophily Combined

Nevertheless, Figure 3 shows that social influence without homophily allows only low levels of diversity at high noise rates. On average of about 80 percent of the population are assimilated by the dominant culture, and monoculture obtains in about two-thirds of all realizations of the stochastic process. This poses the question as to what might happen were we to combine social influence and homophily? Experiment 3 addresses that question. The experiment is identical to experiment 2, except that p_{ij} is no longer fixed at 1 but instead varies with the proportion of features on which i and j have identical traits, as in experiment 1. Experiment 3 is identical to experiment 1 except that influence is social rather than interpersonal. Figure 4 reports the results.

Figure 4 shows the effect of the level of noise on the normalized size of the largest cultural region at the end of the simulation runs, averaged across fifty realizations per condition for three different population sizes. Surprisingly, we do not observe the non-monotonicity evident in experiment 2, even though both experiments assume that influence is social. Figure 4 shows that higher noise increases the size of the largest region across the entire interval that we inspected, for all three population sizes.[6] The reason is that homophily amplifies the stabilizing effect of social influence reducing the influence of dissimilar neighbors. More technically, when p_{ij} = 1 for all i and j, dissimilarity to one's neighbors does not prevent those neighbors from being selected for inclusion in **S**, the set of influential neighbors (see steps 2 and 4 above). In contrast, under the assumption of homophily, p_{ij} varies with the proportion of features on which i and j have identical traits. Cultural perturbation thus has the effect of reducing p_{ij} for interactions in which either i or j is induced to deviate from the local norm. Reducing the influence of dissimilar neighbors lowers the probability that a random cultural mutation will create a bridge between dissimilar cultural regions, which in turn preserves a larger number of cultural regions than would be possible in the absence of homophily.

Like Figure 3, Figure 4 also shows that anomie never arises when influence is social, with or without homophily, even at noise levels as high as .1. As the noise level increases further above .1, local convergence is eventually precluded, but the window within which anomie can be avoided is far wider with social influence than with interpersonal influence. As in experiment 2, we observe the smallest regions when the noise rate is low. The average size of regions is never lower than 6.14 agents (at $N = 100$, $r = r' = 10^{-6}$). At the point where the average of S_{max}/N is at a minimum ($N = 10,000$, $r = r' = 10^{-6}$), the largest region contains on average about 238 agents, and the average region still consists of about 8.2 agents. This indicates robust local convergence both at low and at high noise levels. These results compare to a lower bound of slightly above one agent per region in experiment 1 (which is also the size observed for the network homophily model). For $N = 1,024$, the upper and lower bounds are $S_{max}/N = .146$ to about .3, again a result that is clearly distinct from both monoculture and cultural anomie.

Figure 4 also shows a more robust effect of population size than we observed when social influence was modeled without homophily. Recall that the original Axelrod model predicted the preservation of diversity in very small societies but monoculture in large populations, the opposite of what empirical intuition would suggest, a problem that concerned Axelrod. Experiment 2 identified the origin of this problem in the assumption that influence is interpersonal. With social influence but no homophily (Figure 3), we begin to see an effect of population size and in the expected direction—more diversity in larger populations, but the differences diminish as the rate of noise increases. Figure 4 reports a much more robust effect of population size that persists over the entire range of noise levels that we tested.

It is also apparent from Figure 4 that the combination of social influence and homophily generates cultural diversity that is much more stable under perturbation

than the outcomes in the three previous models with either homophily (KETS and CGES) or social influence (PCN) but not both. Cultural diversity is least stable with $N = 100$, comparable to what we observed for social influence without homophily in Experiment 2. For noise rates at or above 10^{-3}, we obtain S_{max}/N about .84, only slightly smaller than what we observed in experiment 2. However, the improvement becomes much more dramatic as population size increases. For $N = 10,000$ and $N = 1,024$, we observe robust cultural diversity across the entire range of noise levels. For $N = 10,000$, S_{max}/N is never greater than .062, compared to an upper bound approaching 1 without network homophily (experiment 1), .9 with network homophily (see online appendix), and .81 with social influence but without homophily (experiment 2).

As an additional test, we inspected the final outcomes of all of the realizations for all conditions of experiments 1 to 3. The model with social influence and homophily (experiment 3) is unique among the four models that we studied in that the population ended neither in monoculture ($S_{max}/N \geq .99$) nor in anomie (average $S < 3$) under any of the tested conditions, in any of the realizations (details in the online appendix A3).

Nevertheless, we cannot rule out the possibility that monoculture might obtain under conditions that we did not test. In particular, it is possible that monoculture might obtain if the experiment were allowed to continue indefinitely. To test this possibility, we increased the number of iterations tenfold with $r = r' = 10^{-3}$ and all other parameters identical to those in Figure 4. We then measured the change in S_{max}/N between two time points: at the end of the first 10 percent of the iterations and at the end. The first time point corresponds to the number of iterations per agent reported in Figure 4. The second time point occurs after ten times that number of iterations. Between those two time points, the normalized size of the largest cultural region increased from .822 to .936 for $N = 100$ (based on 100 realizations of 100 million iterations each), from .19 to .2 for $N = 1,024$ (based on ten realizations of one billion iterations), and from .0274 to .0296 (based on four realizations of ten billion iterations). These increases, however small, mean that we cannot rule out the possibility of eventual monoculture if the process were allowed to continue indefinitely. The implication is that social influence combined with homophily may explain why diversity has not yet collapsed but does not provide assurance that diversity will not collapse at some point in the future. However close or far that point might be, it is clear that it is vastly longer than would be the case if influence were interpersonal or if interaction were not constrained by cultural similarity.

Discussion

Explaining robust cultural diversity in a connected world is a challenge for formal models of cultural dissemination. Axelrod (1997) showed how local convergence can help to preserve cultural diversity in small populations if interpersonal influence

is combined with homophily, the principle that "likes attract." However, Klemm et al. (2003a, 2003b) showed that the stable cultural regions reported by Axelrod collapse into monoculture when very small amounts of cultural perturbation are introduced. If cultural perturbation rates are slightly higher, dynamic cultural diversity can arise as an equilibrium with both global diversity and local convergence. But experiment 1 shows that this explanation holds for only a very narrow range. If the noise level is too low, global diversity collapses into monoculture, and if it is too high, we fail to get local convergence. Moreover, this window closes as the population size increases, which fails to address a second puzzling result in Axelrod's model: that diversity is possible in small isolated communities but not in large globally connected societies.

The fragility of diversity in the Axelrod model led researchers to look for alternative specifications. We replicated CGES's demonstration that network homophily can prevent cultural drift into monoculture in the conditions assumed by Axelrod. However, when we increased the interaction radius and allowed selection error, network homophily could not prevent the formation of a dominant cultural region, and the window of noise rates within which both monoculture and anomie can be avoided remained nearly as small as in the original Axelrod model. In experiment 2, we also replicated PCN's model, which showed that diversity was more robust when influence was social rather than interpersonal, even without homophily. Anomie was precluded entirely, but not the formation of a dominant cultural region, especially at higher noise rates. Experiment 3 showed that combining homophily with social influence provides a more robust explanation for the persistence of cultural diversity, especially in large populations. With social influence and homophily, local norms become even more resistant to deviant influence compared to social influence without homophily, which in turn makes it even easier for conformists to reverse random deviation from local norms before the deviation can spread.

Long-Run Behavior

Important questions remain that point to new avenues for future research. In his theory of stochastic stability in social dynamics, Peyton Young noted that "it should come as no surprise to find societies that operate for long periods of time in regimes that do not correspond with the long-run predictions of the theory" (Young [1998] 2001, 146). This warns us against concluding that cultural diversity is more robust in equilibrium when influence is social rather than interpersonal. For large populations, the system fails to attain equilibrium even after billions of iterations. Although social influence combined with homophily can inhibit cultural drift toward monoculture by many orders of magnitude, compared to an identical model with interpersonal influence, we cannot rule out that monoculture obtains in equilibrium.

Moreover, our experiments exclude complications that occur in social influence dynamics in the real world, such as heterogeneous "complex networks" (Albert and

Barabási 2002), heterogeneity of agents in demographic characteristics or in individual characteristics such as openness to influence (Deffuant, et al. 2002), or agents' inherent preferences for a particular position in the opinion space (Friedkin and Johnsen 1999). Additional studies are needed to assess to what extent cultural diversity is sustained by social influence in more complex settings.

Empirical Research

Until recently, data on cultural dissemination were rarely sufficient to chart the rate and the direction of change in the level of diversity on a global scale. However, the increasing reliance on computer-mediated cultural transmission is opening up unprecedented opportunities to study the detailed digital records of human behavior on global social networks (Lazer et al. 2009).

Empirical research on large online networks is needed not only to provide better insight into dynamics of cultural diversity but also into the effects of network structures. Theoretical work based on Axelrod's model of interpersonal influence suggests that network topology may importantly affect cultural diversity (Xiao et al. 2009). Future work should explore whether social influence has a similar stabilizing effect across different network topologies, including structures similar to those observed in empirical studies. At the micro level, laboratory experiments are needed to look for evidence of social and interpersonal influence, as well as interaction and network homophily, as fundamental mechanisms of human interaction.

Comparative Statics

Much more research is needed to systematically map the parameter space defined by standard measures used in this and in previous studies (e.g., noise rates, neighborhood and population sizes, and the number of cultural features and traits) as well as other conditions that have received little attention in the modeling literature, such as bounded neighborhoods that are identical for all neighbors, models in which spatial mobility is possible, features that vary in relative salience, and features with metric traits.

Metric Features, Blending, and Negativity

Earlier studies of social influence (French 1956; Abelson 1964) point to another assumption in Axelrod's model that is problematic: that all cultural features are nominal (like religion and language). With nominal features, people are either identical or different, there are no shades of gray. However, cultures can also be distinguished by metric features with degrees of similarity, such as the normative age of marriage or the enthusiasm for jazz. Even religion and language can form nested hierarchies in which some classes are closer to others (e.g., Congregationalists are closer to Unitarians than to Islamic Fundamentalists). Flache, Macy and Takács

(2006) found that local convergence does not lead to global diversity in Axelrod's model if even a single cultural dimension is metric, no matter how many features are nominal. Monoculture is then the ineluctable outcome, even with social influence and homophily. Future work needs to investigate how diversity is possible when metric features are vulnerable to cultural blending.

A possible answer is the negative side of homophily and social influence—xenophobia and differentiation. Almost all research on cultural dissemination has focused exclusively on the positive moments—homophily and attraction—even though empirical research points to the importance of the negative counterparts. Some exceptions are recent studies by Mark (2003), Macy et al. (2003), Jager and Amblard (2005), Baldassarri and Bearman (2007), Flache and Mäs (2008), and Flache and Macy (2011). Negativity may explain why cultural blending on metric features does not lead to the collapse of diversity and how bridges across the boundaries of cultural regions might have the opposite effect than that assumed by Axelrod and those working in the framework he established.

Conclusion

Axelrod's seminal model of cultural influence showed how "individual or group differences can be durable despite tendencies towards convergence" (1997, 222). He pointed to important implications for the study of conflict behavior. Cultural assimilation in multicultural societies may be unlikely as long as cultural influence is based primarily on local interactions within which people choose their interaction partners based on similarity (the homophily principle). Axelrod related this to succession conflicts in previously communist multinational states, which he suggested may be rooted in the lack of cultural assimilation across different national groups within those states. Similarly, the lack of assimilation of immigrant minorities to the national culture of their host countries may perhaps contribute to domestic political conflicts. From this point of view, cultural integration of a multinational or even global society would not be possible without mechanisms that undercut homophily and local interaction and assure sustained exchange of ideas, beliefs, and opinions between culturally dissimilar people. This led Axelrod to emphasize the importance of advances in mass media, transportation, and information technology for the formation of large, integrated cultural regions that extend beyond the national level or, within nations, beyond the level of ethnic groups.

These conclusions are not warranted by the results of Axelrod's research. His model predicts diversity only in extremely small populations, on the order of about 100 members. For societies with thousands of members or more, Axelrod's model predicts cultural assimilation of minorities into a global monoculture. Moreover, subsequent research by KETS showed that diversity cannot be sustained even in very small populations if the model allows for noise. The results suggest that, contrary to Axelrod, either cultural homogeneity or cultural anomie is the inevitable

consequence of the twin mechanisms Axelrod proposed, homophily and interpersonal influence.

Our study shows that it would be premature to dismiss the implications for the study of conflict that Axelrod suggested. We found that cultural diversity can be highly robust, even in large populations, when influence is social rather than interpersonal. Telephone conversations, e-mail exchanges, text messages, and even many face-to-face interactions are dyadic and interpersonal, as assumed by Axelrod and in almost all follow-up research. Dyadic interaction, however, need not imply dyadic influence. With the possible exception of a few classic anticommunist films from the 1950s, it is difficult to imagine that deviants can seduce their network neighbors one at a time, while all the other neighbors are preoccupied with other business. This is a fundamental difference between the spread of disease and most social contagions, as recently noted by Centola and Macy (2007). Whether it is a risky new technology, a controversial belief, a dangerous confrontation with police, an avant garde fashion, or a product whose benefits require that others adopt it as well, people often look around to see what their neighbors are doing before deciding what to do. We have shown that this social influence creates an obstacle for cultural assimilation that makes the persistence of diversity much more likely than previous studies have concluded.

Our work also has important implications for the paradox of group size posed by Axelrod. Building on the counterintuitive result that group size reduces global diversity, Axelrod (1997) suggested that as a ''relevant political territory gets larger, the number of distinct cultural regions can be expected to decline'' (p. 224), with the possible interpretation that the cultural integration that took place within European nations, from the fifteenth century on, may have been fostered by the expansion of these nations into a wider territory. Similarly, Axelrod saw this as being consistent with Huntington's (1993) prominent expectation that the recent push toward globalization entails conflicts between large cultural regions that extend far beyond the national level. Our study has shown how this effect of population size reverses if influence is social rather than interpersonal: the larger the population, the larger the number of distinct cultural regions that persist and the smaller the largest of these regions relative to the overall population.

Finally, our results suggest new hypotheses on the reasons why some cultures appear to be more resistant against assimilation than others. First, societies in which influence tends to be interpersonal rather than social are more prone to become culturally homogeneous. If interpersonal influence is more likely in societies that value individualism and discourage conformity to majority opinion, then our model points to the ironic implication that the preservation of cultural diversity is more likely in conformist than in individualist cultures. The model also carries an important caveat: if individualism leads to a sufficiently high rate of cultural innovation, local convergence may fail to occur, leading not to homogeneity but to cultural anomie.

A second hypothesis links the conditions for cultural homogeneity to the structure of social networks. Social influence can only sustain diversity if there is sufficient

closure in social networks. By closure, we mean the probability that any two neighbors of a randomly chosen individual will also be neighbors of one another (thereby closing the triangle). With low levels of network closure, an individual's neighbors are unlikely to interact with each other, and thus they are unlikely to influence one another to acquire similar cultural traits. This in turn makes it less likely that this individual's neighbors will enforce conformity with a locally dominant trait. Conditions that are unfavorable for network closure, such as sociodemographic heterogeneity in local communities, or relatively high rates of geographical mobility, may therefore also be conditions that are unfavorable for persistent cultural diversity.

"Of course, a simple model can only be suggestive and never definitive" (Axelrod 1997, 223). George E. P. Box said much the same thing: "All models are wrong but some models are useful" (Box and Draper 1987, 424). Our model is almost as simple as Axelrod's, but we believe it is much more suggestive in that it provides a more robust explanation for the persistence of cultural diversity, even in large populations and even in a world that contains noise. Our model is also useful in identifying the importance of the distinction between social and interpersonal influence for understanding how cultural diversity may be able to persist in a rapidly globalizing world.

Authors' Note

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Notes

1. Following Axelrod (1997), we use a very broad definition of "culture" that encompasses political opinions and beliefs, religious and moral values, artistic tastes in painting, music, fashion, cinema, and so on. In short, "culture is taken to be what social influence influences" (Axelrod 1997, 207). He defines a cultural region as a set of contiguous cells with an identical cultural profile that is distinct from all neighbors. Thus, there could be two identical cultural regions as long as the members of each of the two regions have no neighbors in the other region.

2. Cultural evolution in Axelrod's model differs from biological in that change can only occur through crossover since Axelrod does not allow for mutation.

3. The exception is an agent who is located on the boundary of the lattice. These agents can have no more than three neighbors, two of whom must also be on the boundary. PCN use a quadratic Moore neighborhood with up to eight neighbors.

4. Details on our replication of the network homophily mechanism are given in the online appendix A2.

5. A more restrictive criterion would be that the average size of the largest region falls below three ($S_{max} < 3$). We also tested for this criterion and found that it only marginally affects our quantitative results, while the qualitative conclusions remain the same.

6. The only exception is a marginal decline of the average S_{max}/N from .67 to .65 between $r = r' = 10^{-6}$ and $r = r' = 10^{-5}$, for $N = 100$.

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