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Homophily, Cultural Drift, and the Co-Evolution of Cultural Groups

Damon Centola
Institute for Quantitative Social Science, Harvard University, Cambridge, MA
Juan Carlos González-Avella
Víctor M. Eguíluz
Maxi San Miguel
Institute for Cross-Disciplinary Studies and Complex Systems, Campus Universitat de les Illes Balears, Palma de Mallorca, Spain

Studies of cultural differentiation have shown that social mechanisms that normally lead to cultural convergence—homophily and influence—can also explain how distinct cultural groups can form. However, this emergent cultural diversity has proven to be unstable in the face of cultural drift—small errors or innovations that allow cultures to change from within. The authors develop a model of cultural differentiation that combines the traditional mechanisms of homophily and influence with a third mechanism of network homophily, in which network structure co-evolves with cultural interaction. Results show that in certain regions of the parameter space, these co-evolutionary dynamics can lead to patterns of cultural diversity that are stable in the presence of cultural drift. The authors address the implications of these findings for understanding the stability of cultural diversity in the face of increasing technological trends toward globalization.

Keywords: *social networks; cultural diversity; homophily; cultural drift; social dynamics*

Homophily—the principle that "likes attract"—is a prominent explanation for the persistence of cultural diversity. More precisely, homophily is the tendency of people with similar traits (including physical, cultural, and attitudinal characteristics) to interact with one another more than with people with dissimilar

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traits. There are three reasons why homophily is such a powerful force in cultural dynamics, where *culture* is defined as a set of individual attributes that are subject to social influence (Axelrod 1997). Psychologically, we often feel justified in our opinions when we are surrounded by others who share the same beliefs—what Lazarsfeld and Merton (1954) call "value homophily" (Huston and Levinger 1978; Knoke 1990); we also feel more comfortable when we interact with others who share a similar cultural background (i.e., status homophily; Lazarsfeld and Merton 1954; Fischer 1977; Marsden 1987, 1988; Shrum, Cheek, and Hunter 1988). Both of these reasons are forms of choice homophily (McPherson and Smith-Lovin 1987; McPherson, Smith-Lovin, and Cook 2001), where patterns of interaction are driven by preferences for similarity. The third reason, induced homophily (McPherson and Smith-Lovin 1987; McPherson, Smith-Lovin, and Cook 2001), emerges not from individual choice but from influence dynamics that make individuals more similar over time.

While homophily has been studied empirically as an important factor in the formation and differentiation of social groups (Fischer 1977; Marsden 1988; Popielarz and McPherson 1995), there are relatively few formal models that show how homophily functions to create and preserve social differentiation (Axelrod 1997; Mark 1998; Macy et al. 2003). This is because in addition to the principle of choice homophily, social scientists also observe the principle of social influence (i.e., the more that people interact with one another, the more similar they become). This influence process produces induced homophily, in which the disproportionate interaction of likes with likes may not be the result of a psychological tendency but rather the result of continuous interaction (McPherson and Smith-Lovin 1987). When choice homophily (hereafter "homophily") and social influence are taken together, the explanation of cultural diversity poses something of a paradox: "If people who are similar to one another tend to become more alike in their beliefs, attitudes, and behavior when they interact, why do not all such differences eventually disappear?" (Axelrod 1997, 203).

While the processes of homophily and influence can produce global convergence, Axelrod (1997) shows that they can also act as local convergence mechanisms, which produce emergent social cleavages that lead to global polarization. Thus, the answer to the paradox is that as homophily increases, some groups of people do indeed converge on their cultural characteristics; yet if there is enough heterogeneity in the population, this similarity among group members can also make them even more dissimilar from the members of other groups (Duncan, Haller, and Portes 1968; Knoke 1990). Ultimately, this can produce cultural groups that are so dissimilar from one another that their members cannot interact across group boundaries. This not only shows that the simple combination of homophily and social influence can produce and sustain patterns of global diversity (Axelrod 1997) but also that the development of cultural barriers between groups can arise from a process of social self-organization in which emergent differences become significant enough to prevent intergroup contact, even without enmity across group lines.

Building on Axelrod (1997), researchers have found that several factors affect the emergence of cultural diversity; for example, globalization and international communication (Greig 2002), cognitive optimization in social groups (Kennedy 1998), mass media (Shibanai, Yasuno, and Ishiguro 2001; González-Avella et al. 2007), and cultural drift (i.e., random changes in individual traits; Klemm et al. 2003a, 2005). Cultural drift raises the question of whether the above explanation of cultural diversity will hold if actors are permitted to make errors or develop innovations (Axelrod 1997). Surprisingly, Klemm et al. (2003a, 2005) found that if noise is introduced at a low rate (allowing cultural traits to change randomly with a small probability), the basic dynamics of the homophily and influence model will drive the population away from cultural diversity and toward cultural homogeneity.[1] This happens because the introduction of random shocks perturbs the stability of cultural regions, eroding the borders between the groups. This allows the system to find a dynamical path away from the metastable configuration of coexisting cultural domains, toward the stable configuration of a global monoculture.[2] If there is a possibility that small errors or innovative changes will alter even a few individuals' traits, the mechanisms of homophily and influence will be unable to sustain cultural diversity in the long run. Thus, we are faced with the question of whether global monoculture is an inevitable outcome in the presence of cultural drift.

The present article takes up this revised form of Axelrod's (1997) question by developing a model that demonstrates conditions under which local dynamics of homophily and influence can produce and maintain cultural differentiation even under the noisy conditions of cultural drift. Other recent attempts to solve the problem of cultural diversity under drift either fix certain cultural characteristics (Durrett and Levin 2005) or introduce xenophobia into the dynamics (Macy et al. 2003). We preserve the basic homophily and imitation dynamics developed by Axelrod (1997). The key development in our approach is the specification of homophily. While both choice and induced homophily have been primary mechanisms for understanding how distinct cultural groups can form (Axelrod 1997; Mark 1998, 2003; Durrett and Levin 2005), most research in this tradition places an emphasis on the changing distribution, or clustering, of traits over time. However, recent research shows that network dynamics—the changing patterns of social interaction over time—may play an equally important role in understanding the effects of homophily on group formation (McPherson, Smith-Lovin, and Cook 2001). Following this line of research, we introduce network homophily via the coevolution of individual traits and network structure (McPherson, Popielarz, and Drobnic 1992; Lazer 2001; Eguíluz et al. 2005).

In previous models of cultural evolution (Axelrod 1997; Kennedy 1998; Greig 2002; Klemm et al. 2003a, 2003b), the network of social interactions remains fixed, which forces individuals with no cultural traits in common to remain tied to each other in the social network despite having no possibility for interaction. However, in our approach to studying cultural dynamics, if cultural influence processes create differentiation between two neighbors such that they have no cultural traits in common, we allow these individuals to alter the structure of the social network by dropping their tie and forming new ties to other individuals. Thus, in our specification of homophily, the network of social interactions is not fixed (Axelrod 1997; Klemm et al. 2003b) but rather evolves in tandem with the actions of the individuals (Macy 1991; Lazer 2001) as a function of changing cultural similarities and differences (Blau and Schwartz 1984; Marsden 1987, 1988; McPherson, Smith-Lovin, and Cook 2001). Following Klemm et al.'s (2003a, 2003b, 2003c, 2005) use of the level of heterogeneity in the population as a control parameter, our network-based approach allows us to map the space of possible co-evolutionary outcomes and thereby show how network structure and cultural group formation depend on one another. These results allow us to address the question of how stable cultural groups can be maintained in the presence of cultural drift.

A Co-Evolutionary Model of Cultural Dynamics

We use an agent-based model (Axelrod 1997) in which each actor i has its individual attributes defined as a vector of F cultural features; each feature represents a different kind of taste or behavior (e.g., language, religion, music choice, clothing, etc.) and takes its value from a range of q possible traits. Thus, the state of an actor i is a vector of F cultural features $(\sigma_{i1}, \sigma_{i2}, \ldots \sigma_{iF})$, where each σ_{if} corresponds to a cultural trait assigned from the range of integers between 0 and $q - 1$. The length of the vector F represents the social complexity of the population (i.e., the larger F is, the greater the number of cultural characteristics that are attributable to each individual). The number of traits, q, represents the heterogeneity of the population (Blau and Schwartz 1984). The larger q is, the larger the number of possible traits that a given feature can have, corresponding to a greater number of cultural options in the society.

The initial state consists of N agents located in a two-dimensional square lattice with von Neumann neighborhoods (Axelrod 1997; Centola, Willer, and Macy 2005), which allows for easy comparison with previous work (Axelrod 1997; Castellano, Marsilli, and Vespignani 2000; Klemm et al. 2003a, 2005). Each actor is randomly assigned F cultural traits. Agents are neighbors if they are connected by a direct link in the network, where the weight of this link is determined by their cultural similarity, defined below. The dynamics of the model are defined by the following rules:

1. Select an agent i at random from the population. Call i the "active" agent. From among i's neighbors, select a random neighbor j and call this agent the "partner."

2. Calculate the overlap, or cultural similarity, between i and j as the number of features on which i and j have the same trait: $O(i, j) = \sum_{f=1}^{F} \delta_{\sigma_{if}, \sigma_{jf}}$.
3. If i and j share some features in common but are not yet identical (i.e., $0 < O(i, j) < F$), then i and j interact with probability $O(i, j)/F$.
4. Agent i interacts with agent j by choosing a random feature g such that i and j do not already overlap (i.e., $\sigma_{ig} \neq \sigma_{jg}$). The active agent i then sets its trait at feature g to match its partner's trait at feature g (i.e., $\sigma_{ig} = \sigma_{jg}$).
5. If $O(i, j) = 0$, i removes j from his network of social ties T, and randomly selects an agent k, where $k \notin T$, $k \neq j, i$, and adds k to its social network.

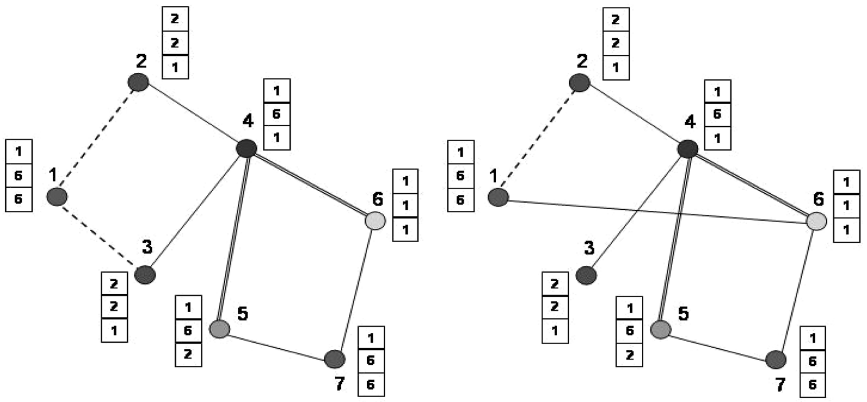
Rules 1 through 4 define the basic homophily and influence model, in which actors who are similar are more likely to interact. Interaction makes actors who are similar become even more similar, increasing the weight of their tie and the likelihood of future interaction. As shown by Axelrod (1997), as some actors become more similar, others become less similar as the dynamics of cultural evolution create widening gaps between the emerging cultural communities. Some neighbors in the social network may become so different from one another that they no longer share any cultural traits in common. When this happens, the weight of the tie between them drops to zero and no longer functions as a means for cultural influence. Rule 5, schematically explained in Figure 1, incorporates network dynamics into the specification of homophily by allowing actors to drop these zero-weight ties. Just like members of a social clique who have grown distant from one another by virtue of interacting with different social groups (Macy et al. 2003), or voluntary group members who share less and less in common as they derive more of their social and cultural influence from outside sources (McPherson, Popielarz, and Drobnic 1992), as social differentiation reduces shared traits, the remaining ties become a vestigial feature of the actors' social histories and are ultimately broken (McPherson, Smith-Lovin, and Cook 2001).

These network homophily dynamics allow the structure of the social network to co-evolve with the dynamics of social influence. If an active individual tries to interact with a neighbor with whom there is zero overlap in cultural features, it drops the tie to this neighbor and randomly forms a new tie to another individual, preserving the overall density of the social network. Taken together, rules 1 through 5 model the co-evolution (Eguíluz et al. 2005) of social structure and individual traits in the emergence of cultural groups.

Model Dynamics

In the absence of co-evolutionary network dynamics (rules 1 through 4 only), the system can evolve either toward complete homogeneity or toward cultural diversity, depending on the level of heterogeneity, q, and the number of cultural features, F

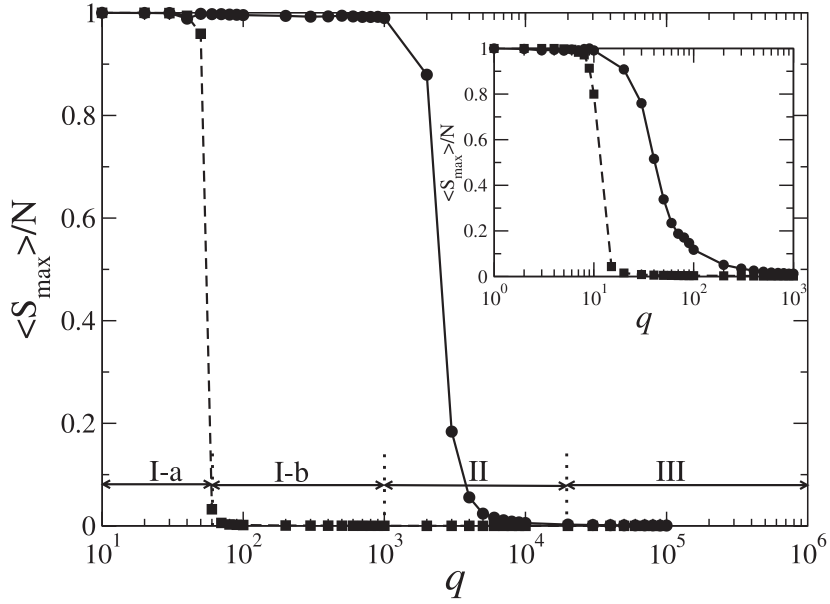
Figure 1
Network Dynamics



Note: Figure 1 illustrates network dynamics for a system with $F = 3$ and $q = 7$. The network on the left (at time t) shows each node with its corresponding vector of cultural features at time t. The network on the right shows the same population at time $t + 1$. The links between nodes are weighted according to their overlap: dashed line for zero overlap, continuous lines for overlap $= 1$, and double line for overlap $= 2$. At time t, the overlap between nodes 1 and 2, $O(1,2)$, is zero, as is $O(1,3)$. At time t, node 1 has been selected as active and node 3 as its partner (rule 1). Rules 2 through 4 imply no changes of state given that $O(1,3) = 0$. Following rule 5, the link between 1 and 3 is removed, and node 1 is randomly linked to a different node. The new link between nodes 1 and 6 (shown in the network on the right) has overlap $O(1,6) = 1$.

(Axelrod 1997; Castellano, Marsilli, and Vespignani 2000). In the limit of large N, for regular lattices, random networks, and small world networks, there is a well-defined transition: For a fixed F, there is a critical value of q, q_c, that corresponds to the transition from global monoculture to cultural diversity (Castellano, Marsilli, and Vespignani 2000; Klemm et al. 2003b, 2003c). Thus, a single parameter—the heterogeneity in the population—controls the dynamics of whether the population evolves toward multiculturalism or toward a global monoculture. This transition is sharp, going from complete monoculture to widespread diversity on either side of the critical value (Klemm et al. 2003c). In Figure 2, the transition is shown by the dramatic change in the average size (normalized by N) of the largest cultural domain, $< S_{max} > /N$, as q increases.[3] When $q < q_c$, the largest cultural domain approximates the size of the entire population $< S_{max} > \sim N$, indicating little or no cultural diversity.[4] However, for $q > q_c$, increased heterogeneity guarantees that the largest cultural domain is only a small fraction of the population ($< S_{max} > \ll N$). Correspondingly, when $< S_{max} > /N$ is small, the number of distinct cultural groups is large.

Figure 2
Comparison of Fixed and Co-Evolving Dynamics

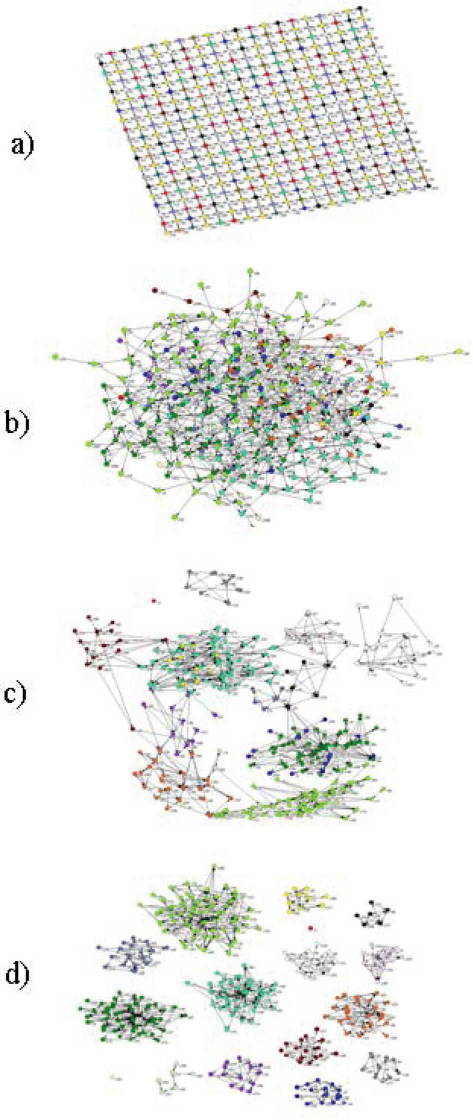


Note: ($F = 10$, $N = 10^4$) For fixed networks (dotted lines, square symbols), the transition to multiculturalism happens for a much lower value of $q (q_c \sim 60)$, than for the co-evolving network (solid line, circular symbols), where the transition happens around $q_c \sim 1000$. The inset shows that this difference is present, but less pronounced for $F = 3$, $N = 1024$ ($q_c \sim 15$).

How does the introduction of co-evolution (rule 5) affect this transition from global monoculture to multiculturalism? Figure 2 shows that introducing network dynamics has the quantitative effect of increasing the critical value of q. Thus, there is a large range of values of q for which multiculturalism is achieved in a fixed network, while co-evolutionary dynamics lead to a monocultural state.[5]

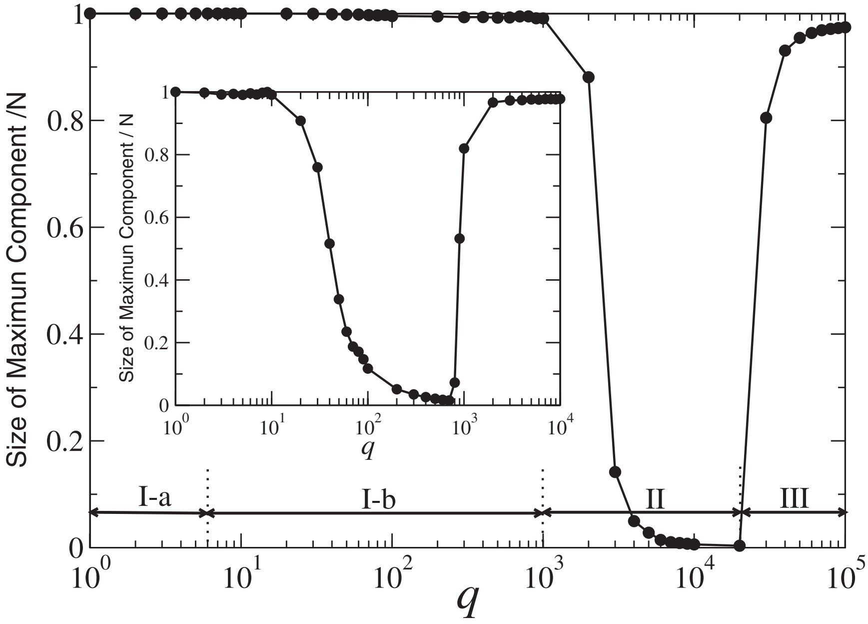
The co-evolutionary dynamics not only affect the critical value of q, but they also dramatically alter the structure of the social network. Depending on the value of q, the network can evolve from a regular lattice into a complex random network with a giant connected cluster or can break apart into multiple components (physical groups) of different sizes. This latter point is quite important, for it means that while cultural diffusion on the fixed network produces boundaries that define the cultural regions, the dynamic network can self-organize into culturally distinct physical groups. This process of self-organization is illustrated in Figure 3. Beginning with a regular lattice (Figure 3a), the system first loses its original structure

Figure 3
Co-Evolutionary Dynamics



Note: Figure 3 illustrates the co-evolution of cultural traits and physical groups in the co-evolving model for $N = 400$, $F = 3$, and $q = 20$. Snapshots of the network are shown at times (a) $t = 0$, (b) $t = 2{,}500$, (c) $t = 25{,}000$, and (d) $t = 500{,}000$.

Figure 4
Size of Largest Component in the Co-Evolutionary Network

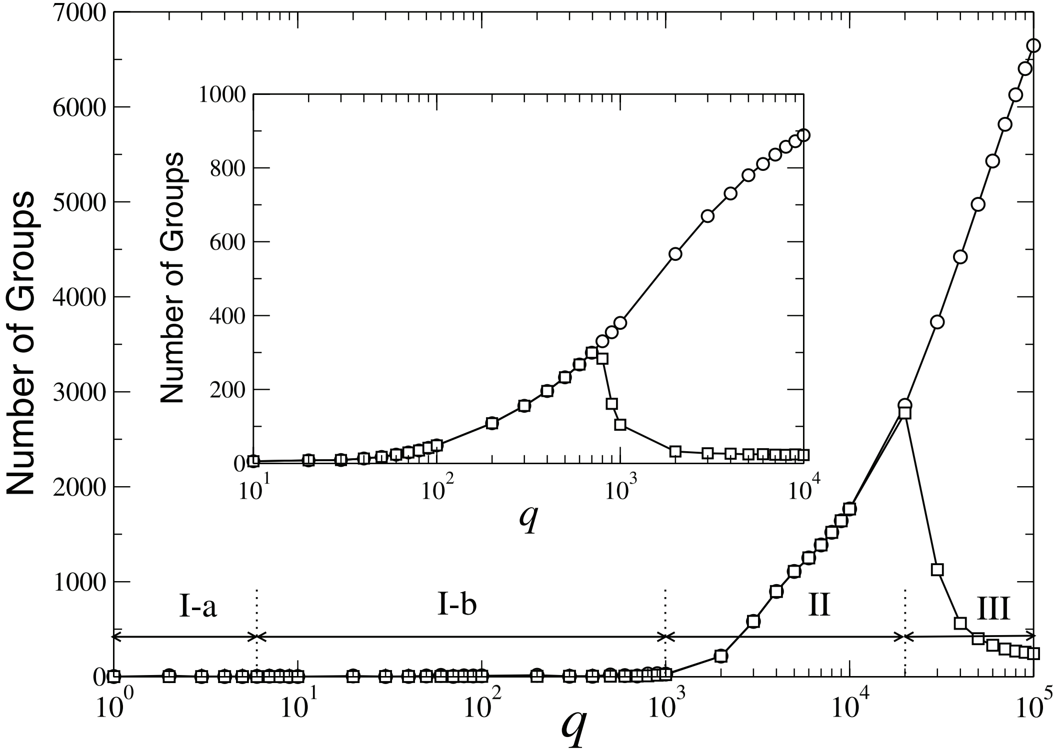


Note: ($F = 10$, $N = 10^4$) The change in the average size of the largest network component (physical group) is shown for increasing values of q. In regions Ia and Ib, $< S_{max} > /N$ remains constant, while in region II it decreases dramatically. In region III ($q > q* \sim 2 \times 10^4$), this trend qualitatively reverses, producing a steep increase in the size of the largest component. The inset shows similar dynamics for $F = 3$ and $N = 1{,}024$ ($q* \sim 7 \times 10^2$).

(Figure 3b), then forms into culturally homogenous regions (Figure 3c), which ultimately become culturally homogenous components (Figure 3d). The colors of the nodes indicate unique cultural groups, which change over time due to the influence process. Assuming the initial network is connected, this process of network self-organization is independent of the initial conditions. We experimented with a variety of initial network topologies (e.g., small world networks, random networks, and regular lattices) and found that the network quickly reorganizes into a random network. More precisely, the final network configuration for different values of q is well described by a Poisson distribution of degree (i.e., the number of links per node).

These network dynamics are surprisingly dependent on the level of heterogeneity in the population, as shown in Figures 4 and 5. Figure 4 illustrates the effects of increasing q on the size of the largest network component, or physical group,

Figure 5
Average Number of Cultural and Physical Groups



Note: ($F = 10$, $N = 10^4$) The number of cultural groups (circular symbols) and physical groups (square symbols) are identical with one another in regions I and II. In region III, cultural and physical groups become decoupled, as the number of cultural groups keeps increasing, while the number of physical groups sharply declines. The inset shows the same dynamics for $F = 3$ and $N = 1{,}024$.

that is produced by the co-evolutionary process. Initially, increasing q causes component size to decrease; however, for higher levels of q, there is a transition above which component size reverses its trend and increases sharply. Figure 5 shows the effects of q on the number of distinct cultural and physical groups. This figure also indicates a sharply curvilinear effect of increasing q. In both figures, these co-evolutionary outcomes are divided into four distinct regions of the parameter space:

Region Ia—values of $q < q_c$ ($q_c = 60$ for $F = 10$ and $q_c = 15$ for $F = 3$) where a global monocultural state is reached in a fixed network.

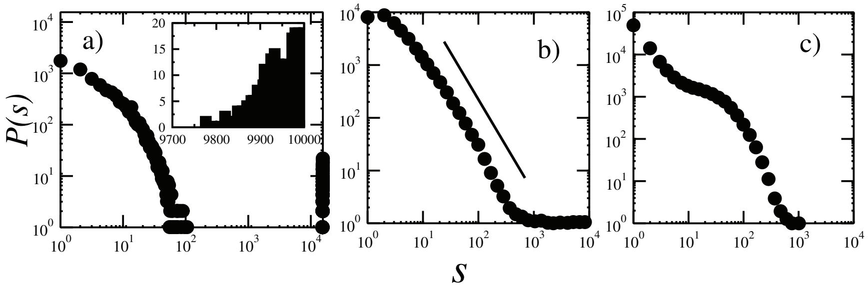
Region Ib—values $q_c < q < q'_c$ for which a fixed network attains cultural differentiation (shown in Figure 1), while a co-evolving network produces a dominant monocultural state.

Region II—values of $q'_c < q < q*$ for which multicultural states are produced in both a fixed network and in a co-evolving network and the number of cultural and physical groups coincide asymptotically in time in a co-evolving network.

Region III—values of $q > q*$, where $q*$ corresponds to a threshold value ($q* \sim 2 \times 10^4$ for $F = 10$, $q* \sim 7 \times 10^2$ for $F = 3$) above which the number of cultural and physical groups no longer coincide.

In region I, the co-evolutionary model produces global monoculture across the entire range of q values. We show this region as subdivided into regions Ia and Ib to compare the fixed network model to the co-evolutionary one. Region Ia is the simplest case, since there is insufficient heterogeneity to allow cultural differentiation—even in a fixed network, there are too few cultural options for cultural diversity to emerge. In region Ib, there is sufficient heterogeneity to allow cultural diversity to emerge in the fixed network; however, in the co-evolutionary model, cultural homogeneity still dominates the population. This is because actors in the dynamic network are able to find paths around local borders by forming new ties. As actors create new links across the population, their ties form a large connected component (technically a giant network component) that allows cultural boundaries to break down and gives rise to a global monoculture. As q increases, we approach region II, in which the dynamic network breaks into multiple components. In Figure 4, region II (approximately $10^3 \approx q'_c < q < 2 \times 10^4$ for $F = 10$ and $N = 10^4$) corresponds to values of q for which there is a gradual decrease in the average size of the largest physical group. In Figure 2, this region corresponds to a gradual decrease in the average size of the largest cultural group. Thus, as the size of the largest component decreases, so does the size of the largest cultural domain. In Figure 5, region II is also shown to correspond to the values of q for which there is a gradual increase of the average number of physical and cultural groups. So as the network breaks apart into multiple components, it also forms into more cultural groups.

Figure 6
Distribution of the Sizes of Physical Groups



Note: ($F = 10$, $N = 10^4$) The x-axis shows the group size S, and the y-axis shows the number of occurrences of groups of size S, $P(S)$. In panel (A) $q = 900$ (region I); panel (B) $q = 3{,}000$ (region II); and panel (C) $q = 5{,}000$ (region II); the points represent the number of occurrences of groups of size S over 500 realizations of the model. In panel A, the group of points on the right ($S \sim 10^4$) indicate that there is always a dominant cultural group that contains most of the population (the inset shows that across realizations of the model, the largest group ranges in size from $S = 9{,}800$ to $S = 10^4$). Panel C shows that there are no groups with $S > 10^3$, and the majority of the population is located in groups ranging from 10 to 10^3 members. Panel B indicates there is a power law decay $P(s) \sim s^{-\alpha}$ with $\alpha \sim 1.44$ (the solid line is plotted as reference) of group sizes, which indicates that there is no characteristic group size for the population.

Computational analyses of the transition between regions I and II show that the critical value of q_c' increases with the size of the population N. Thus, the more people who participate in the cultural exchange, the more heterogeneity is required to prevent assimilation into a global monoculture. Furthermore, we also found that for larger values of F, the critical transition between regions I and II becomes sharper, as seen in the differences in Figures 2 and 4 between the transitions in the insets ($F = 3$) and in the main figures ($F = 10$). For $F = 3$, there is a gradual transition between a dominant culture and abundant cultural diversity. However, for $F = 10$, the size of the largest cultural domain undergoes a sharp transition from a single group occupying nearly the entire population to many small groups of the same size.

Closer analysis shows that for $F = 10$, the distribution of group sizes undergoes an unexpected phase transition as the system moves between regions I and II. Figure 6 ($F = 10$) shows the distribution of group sizes for a system in region I ($q = 900$), deep in region II ($q = 5{,}000$), and intermediate between them ($q = 3{,}000$). The x-axis indicates the size of the group S, and the y-axis indicates the number of clusters of size S, $P(S)$. Each point in Figure 6 is a record of how many times a group of size S occurred in 500 independent realizations of the model. In panel A (region I, $q = 900$), the majority of the population is in a large component, approximately the size of the population ($S \sim N$). This is indicated by the occurrence of groups at the far right side of the panel. Small groups or individual isolates ($S \sim 1$) make up the remainder of the population. Deep in region II (panel C, $q = 5{,}000$), there are no occurrences of groups larger than 1,000, and most groups have a size between 10 and 1,000 individuals. Intermediate between them, there is a transition point (panel B, $q \sim 3{,}000$), where the distribution of group sizes is scale-free (i.e., it follows a power law). This indicates that for this intermediate value of q, there exist cultural groups of all possible sizes, making it impossible to define a characteristic group size for the population.[6] Thus, in region II, there is a complex and surprising transition in the sizes of the cultural groups that substantively affects the cultural composition of the population.

Our model demonstrates a process of group differentiation through which a large heterogeneous group fractures and then consolidates into multiple cliques or subgroups. This process has been documented in the formation of adolescent and adult friendship groups (Cohen 1977; Verbrugge 1977), voluntary organizations (McPherson, Popielarz, and Drobnic 1992; Popielarz and McPherson 1995), social movements (Heckathorn 1996), class identity (Weeden and Grusky 2005), and cultural norms more generally (Latane 2000). As the number of cultural options in a population increases, the average similarity among the members of large heterogeneous groups decreases. Furthermore, as individuals find others like them and grow more similar, emerging cleavages in the large group eventually result in a splintering process, whereby large groups disaggregate into smaller, more culturally specialized ones (McPherson, Popielarz, and Drobnic 1992; Latane 2000).

The key to these homophily dynamics is the changing nature of the social network. Cultural influence and social adaptation processes allow individuals to evolve in the space of cultural ideas and behaviors, changing the social landscape. As people grow apart, the reinforcing effects of reduced similarity and reduced interaction cause old ties to be dropped; reciprocally, new friendships are made with people who share one's current tastes and preferences. Eventually, this process of individual differentiation also creates group consolidation, as detachment from dissimilar people also gives rise to stronger bonds with more similar individuals (Bourdieu 1984). "This tendency for network relations to form between those who have similar social characteristics is known as the homophily principle. Since individuals close to one another on a dimension of social space are similar, homophily implies that ties are local in social space" (Popielarz and McPherson 1995, 701).

In region II, the physical space of the social network is rearranged until all ties are "local in social space." This process produces an emergent social landscape in which discrete social clusters (i.e., components) correspond to distinct trait groups. The more heterogeneity in the population, the more exclusive these trait groups become (Bourdieu 1984).

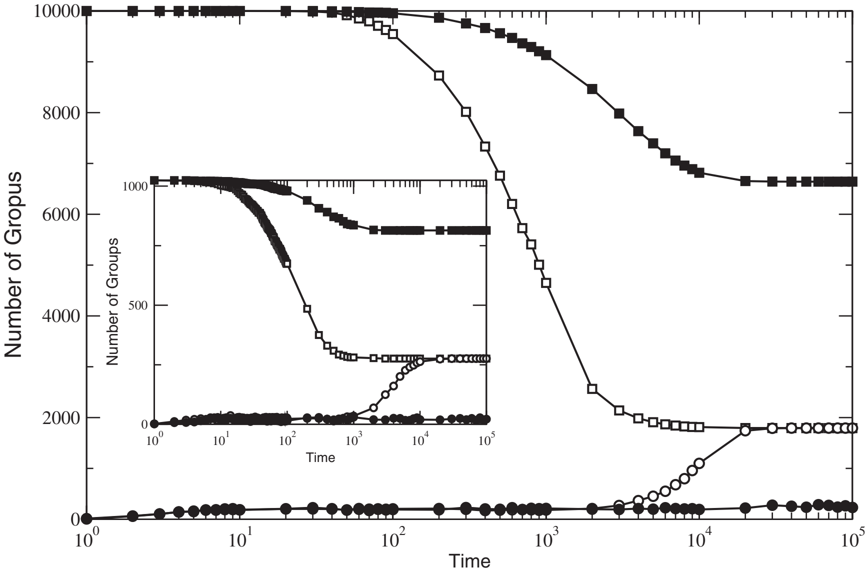
However, this trend of increasing cultural distinction with greater heterogeneity is not continuous. Figure 4 also shows that the trend of decreasing component size, observed in region II, is nonmonotonic in q. Above q^* (region III), the size of the largest component increases sharply. By contrast, Figure 2 shows no corresponding change in the size of the largest cultural group, which continues to decrease for $q > q^*$. In regions I and II, the number of cultural groups matches the number of physical groups, indicating that each component corresponds to a different cultural domain. However, Figure 5 shows that in region III, the number of cultures continues to increase while the number of network components starts to decrease. Thus, in region III, the dynamics of cultural group formation decouple from the dynamics of network formation.

This indicates that q^* represents a transition in the dynamics of cultural evolution past in which social structure does not determine the formation of cultural groups. This is certainly anomalous, since from the definition of our dynamical model, physical and cultural groups are expected to coincide asymptotically. Figure 7 sheds light on this anomalous result by examining the time evolution of network groups (circles) and cultural groups (squares) for values of q above (solid) and below (empty) q^*. First, we observe that both above and below q^*, the dynamics of network evolution (physical group formation) is slower than the dynamics of cultural group formation. For $q < q^*$, the number of cultural groups (empty squares) stabilizes at approximately $t = 4{,}000$, but the number of physical groups (empty circles) does not finally converge until $t = 20{,}000$. For $q > q^*$, the trend is similar, with cultural groups (solid squares) stabilizing at around $t = 20{,}000$; however, the number of physical groups (solid circles) fails to converge.

This failure of the network to converge highlights the primary difference between the behavior of the system above and below q^*. As heterogeneity increases, there is an excess of cultural possibilities, and it becomes less likely that any two actors will have any traits in common. Above q^*, the large number of cultural possibilities overwhelms actors in a finite system, making it difficult for them to find any overlapping traits with one another. As the size of q becomes of the order NF (system size times number of features), the number of possible traits is so much larger than the number of instantiated traits at any given time that the probability of individuals having any cultural overlap approaches zero. The consequence is that co-evolutionary dynamics result in actors continuously breaking links and searching for new partners in the network, without ever reaching a stationary configuration.

Thus, in region III, the abundance of cultural options overwhelms the population, creating "anomic" (Durkheim 1997 [1897]) actors, who develop unlikely combinations of cultural features that prevent them from interacting with anyone. While some actors are able to form into homophilous clusters, the anomic actors perpetually add and drop ties. When $q > q^*$, the largest component in the network consists of this disenfranchised group of actors who are unable to establish

Figure 7
Average Number of Groups as a Function of Time



Note: ($F = 10$, $N = 10^4$) For $q < q*$ ($q = 10^4$ empty symbols), the number of cultural groups (empty square symbols) and the number of physical groups (empty circular symbols) converge after approximately 2×10^4 time steps. For $q > q*$ ($q = 10^5$ solid symbols), cultural groups (solid square symbols) and physical groups (solid circular symbols) never converge. The inset shows the same dynamics for $F = 3$ and $N = 1{,}024$. ($q = 500$ for empty symbols and $q = 6{,}000$ for solid symbols).

memberships in any of the homophilous social clusters. With increasing heterogeneity, the number of anomic actors increases, as does the size of this component, until the entire population forms a single network that is simply a buzz of adding and dropping ties with no mutual influence or lasting relationships. The overabundance of cultural options actually prevents the formation of cultural groups and thus eliminates the forms of social diversity that heterogeneity was thought to help create. This suggests that—in addition to previous findings that increased heterogeneity facilitates the maintenance of cultural diversity—under certain conditions, limiting cultural opportunities may also facilitate the preservation of diverse cultural groups.

In summary, holding the system size and the number of features constant, we can thus identify the complex ways in which heterogeneity controls the dynamics of cultural co-evolution. For $q < q'_c$, there is a dominant connected component of the social network where the cultural patterns converge on a global monoculture.

For $q'_c < q < q*$, the network breaks off into components that correspond to distinct cultural groups. Finally, for even greater values of heterogeneity ($q > q*$), network evolution and cultural evolution decouple, as the size of the largest component increases dramatically while cultural groups fragment into ever smaller and ultimately idiosyncratic patterns of traits.

Finally, it is worth commenting on the robustness of our findings with respect to the specific co-evolution rule (rule 5) that we have implemented. With this rule, the cultural traits of individuals and the structure of the social network co-evolve on the same time scale. However, this temporal constraint can be relaxed. Different time scales for the evolution of cultural traits and network ties can be introduced by a parameter p that determines the probability with which rule 5 is applied in a time step. That is, each time an individual is activated to participate in a cultural interaction, there is a probability p that a link of zero overlap is removed and a new random link is established. Thus far, we assume that $p = 1$. As a robustness check, we have tested our results for other values of p. We found that the same results are produced for values of $p > 0$, with the difference that the time needed to reach the final configurations becomes much larger as p becomes small. Thus, relaxing the assumption that $p = 1$ has the effect of increasing the transient time of the dynamics without affecting the final outcome.

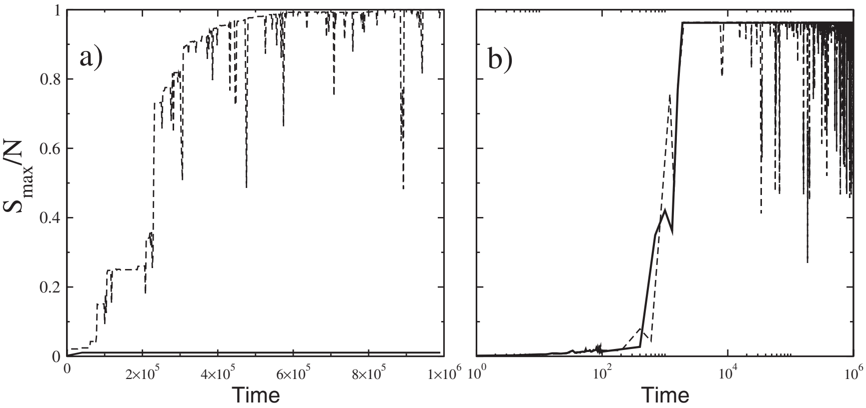
Cultural Drift and Co-Evolution

This analysis of the co-evolutionary dynamics suggests that in region II, where nontrivial multicultural states survive in a co-evolving network, the co-evolutionary cultural processes of homophily and influence may in fact stabilize the co-existence of distinct cultural regions even in the presence of continuous stochasticity. Following Klemm et al. (2003a, 2005), we add cultural drift to the evolutionary dynamics by adding noise in the form of continuous random shocks, as defined by the following rule:

With probability r, perform a single feature perturbation. A *single feature perturbation* is defined as randomly choosing an agent i from the population, $i \in \{1, \ldots, N\}$; randomly choosing one of i's features, $f \in \{1, \ldots, F\}$; then randomly choosing a trait s from the list of possible traits, $s \in \{1, \ldots, q\}$, and setting $\sigma_{if} = s$.

Depending on whether the rate of perturbation r is less than or greater than the time scale on which the homophily and influence dynamics operate, the system will either be slightly perturbed on a regular basis (small noise rate), or the system will be constantly flooded with noise (large noise rate) and unable to reach any kind of equilibrium. In fixed networks, there is a critical value of the noise rate r_c above which noise dominates the behavior of the system (Klemm et al. 2003a). We are here interested in the small noise rate limit ($r < r_c$), which tests the stability of cultural diversity in the presence of cultural drift.

Figure 8
Effect of Cultural Drift on Multicultural Stability in Region Ib

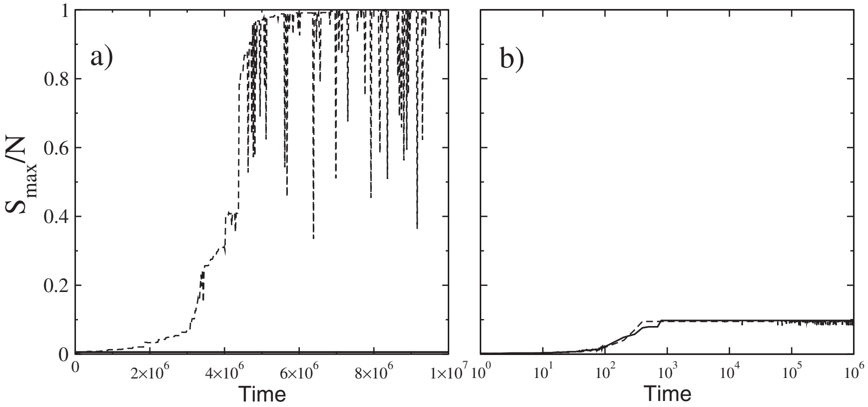


Note: ($F = 3$, $N = 1{,}024$, $q = 20$). Panel A shows a fixed network in region Ib, with no noise ($r = 0$, solid line) and cultural drift ($r = 10^{-5}$, dashed line). The solid line (at the bottom) shows very high cultural diversity, while the dotted line shows the emergence of a global monoculture. Panel B shows the dynamics for no noise ($r = 0$, solid line) and drift ($r = 10^{-5}$, dashed line) in a co-evolving network in region Ib, where there is insufficient heterogeneity to produce cultural diversity.

As a benchmark for comparison, Figure 8 shows the effects of cultural drift in region Ib for a fixed network and for a co-evolutionary model. For a fixed network (Figure 8a), we observe that without cultural drift ($r = 0$, solid line) the system stabilizes in a multicultural state $S_{max} \ll N$ for the whole duration of the simulation. However, cultural drift ($r = 10^{-5}$, dashed line) drives the system toward a monocultural state, where $S_{max} \sim N$ (Klemm et al. 2003a, 2005). It is worth noting that this monocultural state is not fixed, as perturbations take the system in random excursions away from and then back to any of the q^F equivalent monocultural states. As a new trait percolates through the network, the size of the largest cultural group drops as more people adopt the new trait. However, as even more people adopt the trait, the size of the largest group increases again until cultural uniformity is restored. For a co-evolving network (Figure 8b), we observe that after an initial transient, the system orders itself in a monocultural state. This happens in the same time scale with noise (dashed line) and without noise (solid line). As in the fixed network, cultural drift causes random excursions from the final monocultural state, only to return to another one.

A more interesting effect is shown in Figures 9a and 9b, which correspond to region II. For the fixed network (Figure 9a), the results are the same as in region Ib: Without noise (solid line), the system stabilizes with high levels of heterogeneity,

Figure 9
Effect of Cultural Drift on Multicultural Stability in Region II

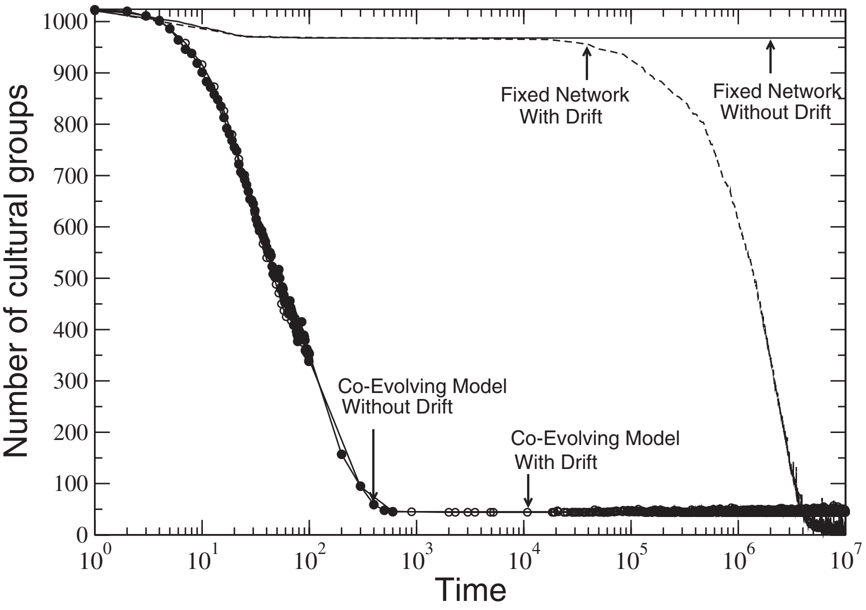


Note: ($F = 3$, $N = 1{,}024$, $q = 100$). Panel A shows a fixed network in region II, with no noise ($r = 0$, solid line) and cultural drift ($r = 10^{-5}$, dashed line). Once again, the solid line (at the bottom) shows very high cultural diversity, while the dotted line shows the emergence of a global monoculture. Panel B shows the dynamics for no noise ($r = 0$, solid line) and drift ($r = 10^{-5}$, dashed line) in a co-evolving network in region II. The co-evolving model produces the same level of cultural diversity (and same number of groups), both without noise and in the presence of cultural drift.

but with noise (dashed line), the system reaches a homogeneous state. As before, noise-induced excursions away from monoculture give rise to changes in the cultural makeup of the group, but the system always returns to a monocultural state. For the co-evolving network (Figure 9b), we observe that in the absence of cultural drift (solid line), the co-evolution model quickly finds a stable state and then remains in that state for the rest of the simulation. When cultural drift is added to the co-evolution model (dashed line), not much happens. The model with noise reaches a stable state in about the same time, and with S_{max}/N of about the same size, as it does without noise. Small perturbations occasionally propagate through the groups, causing shifts in their cultural identities. However, the network structure, the number of physical groups, and the composition of the groups remain unchanged.

Figure 10 shows the number of cultural groups corresponding to Figure 9. As expected, the fixed network without noise (solid line) stabilizes with a large number of cultural groups, but when noise is added (dashed line), the number of cultural groups drops to one. Conversely, for the co-evolving network both without noise (solid circles) and with noise (open circles), diverse cultural groups stabilize in about the same time and remain intact throughout the simulation. While cultural

Figure 10
Time Evolution of Number of Cultural Groups



Note: ($F = 3$, $N = 1{,}024$, $q = 100$) The number of cultural groups in the fixed (no symbols) and co-evolving (circular symbols) networks are shown in the time series in Figure 9. For fixed networks without noise (solid line), the number of cultural groups remains high, while in the presence of cultural drift (dashed line), the number of cultural groups drops to 1. For co-evolving networks with cultural drift (empty circular symbols) and without it (solid circular symbols), the same number of cultural groups form and are maintained.

drift may cause slight changes in the internal culture of the groups—either through perturbations occurring, then dying out, or through perturbations successfully propagating through the cultural groups—the membership of the cultural groups remains distinct. Without cross-cutting (Blau and Schwartz 1984) ties between these groups, there are no opportunities for new cultural exchanges to incite cross-border interaction between cultural groups. Their isolationism guarantees that they can maintain their cultural distinctiveness—dynamic though it may be—even in the face of persistent cultural drift.

To understand why cultural drift does not cause cultural groups to break down, it is necessary to recall that groups will only break down if they form links to other groups. However, new links are only made when existing ties are dropped. Thus, the stability of groups in the dynamic model hinges on the low likelihood that an actor will drop a social tie, which is equivalent to the likelihood of having zero overlap with a fellow group member. Once groups have formed, the local processes of homophily and influence create cultural consensus within the group. Thus, for an actor to have zero overlap with one of its neighbors, a sequence of perturbations must occur such that an actor goes from complete overlap to zero overlap. A lone perturbation on one feature will leave the altered actor with a very high level of similarity with its neighbors. Thus, a single perturbation will result in either the new cultural feature reverting to its original state (if the altered actor is influenced by its neighbor) or the new cultural feature being adopted by a neighbor (if the altered actor influences its neighbor). In both cases, the dynamics of homophily and influence guarantee that the local group will achieve cultural consensus on the newly introduced feature, either through its elimination or its adoption.

For similarity between neighbors to decline, an actor with a new cultural feature must keep the cultural feature without it either being adopted or eliminated, while a second perturbation occurs, either to the originally altered actor or to one of its neighbors. This second perturbation must occur on a separate cultural feature and must lessen the overlap between the two neighbors. Once again, no influence can take place; otherwise, their similarity will increase, leading toward the absorption or elimination of the new traits. This sequence of perturbations must occur, without interruption by the processes of local influence, F times for two culturally identical neighbors to develop zero overlap. The probability of this occurring is roughly $1/N^F$, or the chance that a single agent will be perturbed F times in a row on a different feature each time. The probability is even lower if we consider that none of these perturbations can match any of the neighbors' current traits. For the systems we have been studying ($N = 10^4$) with $F = 10$, the chances of such an event are less than one in 10^{40}. Furthermore, for the noise levels used here and elsewhere (Klemm et al. 2003a, 2005) to represent cultural drift, the model dynamics operate at a much faster time scale than do the perturbations (on average, all actors are activated ten times between each global perturbation), making the probability that such a sequence of perturbations could occur before homophily and influence dynamics would recover cultural consensus infinitesimally small. Thus, at least during time scales that are quite large as compared with the time scale of cultural convergence (approximately 10^3), multicultural states in co-evolutionary systems are robust against cultural drift.

Discussion

In many respects, social and cultural trends toward broad cultural integration are increasing (Greig 2002; Brady, Beckfield, and Zhao 2007). Communication technologies, such as phone, fax machine, and now e-mail, make rapid exchange of ideas and information easy across great distances (Rogers 1971, 1995). Similarly, cultural influences are now regularly shared on a global scale, as international travel, tourism, and education make the world smaller and invite the exchange of cultural traits (McNeill 1988; Foster 1991; Elkins 1997). These trends in the globalization of culture have been furthered by the advent of the Internet (Blossfeld et al. 2005; Brady, Beckfield, and Zhao 2007), which provides nearly instantaneous access to people and ideas worldwide. However, the Internet may also be one of the most profound contemporary arenas for understanding the processes of cultural differentiation.

Recent studies of the behavior of participants in online communities suggest that group formation processes and the emergence of friendship cliques in online environments may exhibit the same co-evolutionary dynamics as those found in our model. Backstrom et al. (2006) found that interactions in the dynamic social networks of online communities produced distinct social groups with densely knit strong ties (Granovetter 1973) within social clusters. These emergent groups serve both to reinforce the existence of social ties within clusters and to maintain group identity and shared practices. These findings are particularly salient to our results, because the Backstrom et al. (2006) study is one of the few studies of social interaction in which the dynamics of adding and dropping ties has been closely observed in the formation of communities. Their results show not only that distinct cultural clusters emerge through endogenous interaction but also that these groups are highly stable.

This trend in online populations suggests that even in the virtual world, network homophily governs the dynamics of cultural co-evolution. People have a preference for interacting with others who share similar traits and practices (Homans 1962; McPherson, Smith-Lovin, and Cook 2001), which naturally diversifies the population into emergent social clusters.

Our results thus reveal an optimistic implication of these preliminary findings from online communities: Despite the growing technological trends toward increased connectivity and globalization, social diversity can be maintained even in highly connected environments. For thousands of years of human history, the emergence and maintenance of group boundaries has sustained the diversity of cultural practices across different populations (Barth 1998 [1969]; Durkheim 2001 [1912]; Boyd and Richerson 2005). In modern online communities, similar patterns of diversification emerge, and for a similar reason: The homophily principle actively constrains the communities to which we belong and the people with whom we choose to interact, share ideas, and adopt our patterns of life (Popielarz and McPherson 1995; McPherson, Smith-Lovin, and Cook 2001). The results from our model show that through the dynamics of network co-evolution, these patterns of preferential interaction of like with like produce cultural pockets whose identity and ideas, though flexible, are nonetheless stable from dissolution into a homogeneous global culture. While trends toward globalization provide more means of contact between more people, these same venues for interaction also demonstrate the strong tendency of people to self-organize into culturally defined groups, which can ultimately help to preserve overall diversity.

Conclusion

Our study of cultural differentiation introduces network homophily into the dynamics of cultural interaction. This co-evolutionary model formalizes the idea that patterns of social interaction change with processes of social influence. The co-evolution of network structure and cultural traits reveals a complex relationship between heterogeneity and the emergence of diverse cultural groups, indicating four qualitatively distinct regions of the parameter space. In region Ia, a large component of the network remains connected, and both fixed and co-evolutionary dynamics lead to a dominant monocultural state in the presence of noise. In region Ib, culturally diverse groups can form in the fixed network, but they are unstable and quickly collapse back into global monoculture in the presence of cultural drift. However, in region II, cultural groups can form in the dynamic network, and these groups are stable even in the presence of continuous stochastic shocks.

Consistent with the results of Popielarz and McPherson (1995), in region II, the interaction of homophily and influence produces a niche structure whereby peripheral members are either absorbed into the core beliefs of the social group (by influence) or are forced out of the social group (by zero overlap). It is significant, however, that these social niches are not produced through competition or selection pressure (cf. Popielarz and McPherson 1995) but through the mechanisms of homophily and influence in a co-evolutionary process. Thus, even in the absence of selection pressures, a population can self-organize into stable social niches that define its diverse cultural possibilities.

We also found that as heterogeneity increases, q approaches the threshold at which it enters region III. These very high levels of heterogeneity are empirically unrealistic in most cases; however, they warn of a danger that comes with increasing options for social and cultural differentiation, particularly when the population is small or there is modest cultural complexity. Unlike cultural drift, which causes cultural groups to disappear through growing cultural consensus, a sudden flood of cultural options can also cause cultural groups to disappear; but instead of being due to too few options limiting diversity, it is due to excessive cultural options creating the emergence of highly idiosyncratic individuals who cannot form group identifications or long-term social ties.

Notes

1. Kennedy (1998) finds a similar result when homophily is eliminated from the cultural diffusion model. He shows that when interactions are not constrained by homophily, social influence dynamics lead to a homogenous state with a single global culture. What is more surprising is that even with homophily, cultural drift will inevitably drive the system to a global monoculture.

2. Klemm et al. (2003a, 2005) also found that if noise acts at high rates, it overwhelms the dynamics of the model and leads to a state in which distinct cultural regions never form. In this

"disordered noise regime," cultural diversity persists, but only as a random pattern of continuously changing traits.

3. Averages reported throughout the article are ensemble averages over 100 realizations with different random initial conditions.

4. The critical value q_c is determined as the value of q for which the fluctuations in the ensemble values of S_{max} are maximum.

5. Figure 2 shows results for $F = 10$ (Klemm et al. 2003a, 2003b, 2003c) and $F = 3$. Results are qualitatively similar, but the transition for $F = 3$ in a co-evolving network occurs for lower values of q.

6. More technical analyses of the transition between region I and region II were performed using methods from the theory of phase transitions; however, they provided little additional insight beyond the present analysis.

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