Diversity and Community Can Co-exist

Alex Stivala, Garry Robins, and Yoshihisa Kashima

Melbourne School of Psychological Sciences

The University of Melbourne

Michael Kirley

Department of Computing and Information Systems

The University of Melbourne

Author Note

Work by Alex Stivala was funded in part by the Asian Office of Aerospace Research and Development (AOARD), grant number FA2386-15-1-4020. This research was supported by Australian Research Council (ARC) grant number DP130100845 and Victorian Life Sciences Computation Initiative (VLSCI) grant numbers VR0261 and VR0297 on its Peak Computing Facility at the University of Melbourne, an initiative of the Victorian Government, Australia. We also used the University of Melbourne ITS Research Services high performance computing facility and support services.

Correspondence concerning this article should be addressed to Alex Stivala, Melbourne School of Psychological Sciences, The University of Melbourne, VIC 3010, Australia. Email: stivalaa@unimelb.edu.au

Abstract

We examine the (in)compatibility of diversity and sense of community by means of agent-based models based on the well-known Schelling model of residential segregation and Axelrod model of cultural dissemination. We find that diversity and highly clustered social networks, on the assumptions of social tie formation based on spatial proximity and homophily, are incompatible when agent features are immutable, and this holds even for multiple independent features. We include both mutable and immutable features into a model that integrates Schelling and Axelrod models, and find that, even for multiple independent features, diversity and highly clustered social networks can be incompatible on the assumptions of social tie formation based on spatial proximity and homophily. However, this incompatibility breaks down when cultural diversity can be sufficiently large, at which point diversity and clustering need not be negatively correlated. This implies that segregation based on immutable characteristics such as race can possibly be overcome by sufficient similarity on mutable characteristics based on culture, which are subject to a process of social influence, provided a sufficiently large "scope of cultural possibilities" exists.

Keywords: cultural dissemination, social networks, diversity, agent-based modeling

Diversity and Community Can Co-exist

Sense of community and respect for human diversity are two separate, although inter-related, goals of community psychology. On one hand, it is generally well-established that homophily, a preference for similar others, is a basic organizing principle in the creation of social ties between people (e.g., McPherson, Smith-Lovin, & Cook, 2001). Furthermore, when one person has a social relationship with a second and also a third person, there is a well-known tendency for the latter two to form a social relationship as well (e.g., Heider, 1958). This is called network closure or triadic closure ("the friend of my friend is my friend"). Network closure leads to effective norms and trustworthiness, according to an influential conceptualization of social capital (Coleman, 1988), of which a "sense of community" (Townley, Kloos, Green, & Franco, 2011) is one aspect. The presence of network closure, then, may be taken as one of the indicators of a stronger sense of community (Neal, 2015; Neal & Neal, 2014). On the other hand, those who are different from each other are less likely to form social relationships and closed social networks. In other words, human diversity appears to be antithetical to the formation of closed network structures which facilitate a sense of community. Then, can a "sense of community" form in diverse neighborhoods, where a high level of diversity precludes the formation of many homophilous social ties (Townley, Kloos, Green, & Franco, 2011)? In a recent paper, Neal and Neal (2014) argued that this is unlikely. In the present paper, however, we suggest that this conclusion is premature, and that it is not impossible for sense of community to emerge in diverse neighborhood in the long run under some circumstances.

The Neal and Neal Model of Diversity and Community

Neal and Neal (2014) used agent-based modeling to argue that diversity (defined as a high degree of integration of two different "types" of agents in a spatial neighborhood) is incompatible with a “sense of community” (defined specifically as the clustering coefficient of the social networks that are formed in the model), under the assumption that agents form friendships with a tendency for homophily and spatial proximity (Neal & Neal, 2014). In this model each agent is only of a single “type” with two possible values, and the types are fixed. So although the types are “assumed to be perceived or socially constructed as different by those involved” (Neal & Neal, 2014, p. 4), they are not susceptible to change by a process of social influence (or anything else). Neal and Neal (2014) give as an example that the “type” could represent race, ethnicity, socioeconomic status, or religion, but stress that their models “should not be viewed narrowly as models of the effect of racial diversity, but as models of diversity on any socially consequential characteristic” (Neal & Neal, 2014, p. 4).

The agent-based model in Neal and Neal (2014) consists of two phases. The first stage is based on the Schelling model of segregation (Schelling, 1969, 1971). In this model, agents, which are of one of the two types (50% each), are initially placed randomly on a lattice. Based on a preference for similar neighbors (the same for each agent), the agents then move until their preferences are satisfied, in that they have few enough neighbors of a different type to satisfy their preference. In this case, the amount of social diversity for each agent is taken as the fraction of dissimilar neighbors. The main result of the Schelling model is that a small preference for similar neighbors in fact leads to a pattern of segregation with a much lower level of neighborhood diversity than that required to satisfy the original preference. In the Neal and Neal (2014) model, agents continue to move until a desired level of spatial integration is achieved. In the second stage of the Neal and Neal (2014) model, a social network is created using a logistic selection function for the probability of a tie between any two agents, based on their similarity of type and their geographical proximity. Using this model, Neal and Neal (2014) find a negative correlation between diversity and sense of community as indexed by the clustering coefficient (Watts & Strogatz, 1998), that is, the level of triadic closure, of the social network, for any realistic levels of homophily and proximity.

That diversity and sense of community are almost always negatively correlated is a provocative conclusion that has significant implications for the theory and practice of community psychology. However, before we accept this as a *fait accompli*, we suggest that the assumptions of Neal and Neal's agent-based model should be considered carefully. In particular, we argue that this conclusion does not always hold, and that it stems from the Schelling model's assumption that the attribute that determines agent type is immutable. In contrast to the Schelling model of segregation, however, there is another similarly influential agent-based model due to Axelrod (1997), which does not assume attribute immutability. By integrating Neal and Neal's (2014) modified Schelling model with the Axelrod model, we show that diversity and community are not always incompatible, and that there are some circumstances in which diversity and sense of community are unrelated or even positively correlated.

The Axelrod Model of Cultural Dissemination

The Axelrod model simulates the dynamics of cultural dissemination on the assumptions of homophily and social influence. Here, an agent is modeled to have an F-dimensional vector of attributes (features), each of which can take one of q possible values (traits). The cultural similarity of two agents is then the number of features they have in common (that is, the number of features which have the same trait). Initially the agents, one at each lattice site, are assigned traits in their culture vectors uniformly at random. The dynamics of the model are that at each step, a randomly chosen agent interacts with a randomly chosen one of its four immediate neighbors, with a probability proportional to their cultural similarity (homophily). The interaction consists of a randomly chosen feature with a trait that differs between the two agents (if there is such a feature) being changed so that it becomes identical (social influence). In this way, the Axelrod model allows for agent attributes to change due to social influence. As similar agents interact with each other, and they become increasingly similar as they interact, the model suggests that similarity begets similarity.

However, an intriguing property of the Axelrod model is that despite the fact that interacting agents become increasingly similar, depending on the initial diversity, or “scope of cultural possibilities” (Axelrod, 1997) controlled by the values of F and, particularly, q, the model will converge to either a monocultural state, in which all the agents have the same culture, or a multicultural state, in which culturally segregated regions emerge, so that regions of agents with the same culture form, and agents on the borders of these regions can no longer interact with each other as they do not share any cultural features.

The Axelrod model has been extended in many ways, including its operating on static social networks (Guerra, Poncela, Gómez-Gardeñes, Latora, & Moreno, 2010; Konstantin Klemm, Víctor M Eguíluz, Raúl Toral, & Maxi San Miguel, 2003; Xiao, Ye, Wang, & He, 2009), or with the co-evolution of a social network (Centola, González-Avella, Eguíluz, & San Miguel, 2007; Vazquez, González-Avella, Eguíluz, & San Miguel, 2007), and agent migration (Pfau, Kirley, & Kashima, 2013). The Schelling and Axelrod models were combined by Gracia-Lázaro, Lafuerza, Floría, and Moreno (2009), who created a model in which empty sites are introduced on the lattice (fully occupied in the original Axelrod model), and agents that are more dissimilar than a threshold “intolerance” value when they attempt to interact migrate to a randomly chosen empty site. This intolerance threshold is similar to the preference for similar neighbors in the Schelling model when $F = 1$, and the model then reduces to a version of the

Schelling model (Gracia-Lázaro et al., 2009). Gracia-Lázaro et al. (2009) found that for small densities of empty sites, a fragmented multicultural state appears, with isolated monocultural domains (for small enough *q*). With a high enough intolerance value, higher values of *q* will again lead to global monoculture. This model was further extended by random re-wiring of links between agents, while maintaining constant average degree (Gracia-Lázaro, Quijandría, Hernández, Floría, & Moreno, 2011), and allowing the tolerance threshold to vary between agents (Gracia-Lázaro, Floría, & Moreno, 2011).

Present Study

In this paper, we investigate the effect of allowing the agents to have both mutable and immutable features. The *mutable features*, as used in the original Axelrod model and its variations, can change over time due to social influence: “Culture is taken to be what social influence influences.” (Axelrod, 1997, p. 207). They may represent, for example, tastes, opinions, or attitudes, such as a preference for a certain genre of music, support for a particular football team, or style of dress. The *immutable features* represent those attributes that cannot change, such as race or ethnicity, or are at least unlikely to change by a process of social influence, such as socioeconomic status. These represent the type of individual attributes used in the Schelling model and by Neal and Neal (2014).

By incorporating both types of attributes into an extended Axelrod-Schelling model, we can investigate the hypothesis that, by allowing the processes of homophily and social influence to operate on mutable features, the apparent incompatibility of diversity and social network clustering (“sense of community”) can be overcome. That is, can social influence, operating on mutable characteristics, allow the possibility of a situation in which diversity and sense of community can both exist? If so, this allows renewed hope that community psychologists can help to create situations in which both respect for diversity and a strong sense of community are fostered. Thus, the present paper directly addresses the vital question for community psychology, i.e., the community-diversity dialectic, as described by Townley et al. (2011) and recently investigated by Neal and Neal (2014) using agent-based modeling.

Methods

We used agent-based modeling to investigate the relationship between diversity and social network clustering. The well-known Schelling and Axelrod models already discussed are examples of agent-based models, and in general such models are a useful technique to help explain how complex phenomena at a large scale can arise from relatively simple local interactions (Conte et al., 2012; Macy & Willer, 2002).

We created two models, both of which contain N agents on an L x L lattice ($N < L^2$). The first model is a further extension of the Schelling model with social network described in Neal and Neal (2014). This model allows us to investigate the effects of having more than one attribute, but as it is fundamentally a Schelling model, the attributes are all immutable. The second model is a further extension of an Axelrod-Schelling model (Gracia-Lázaro et al., 2009), which allows us to examine the effect of having both mutable and immutable attributes.

All models are implemented in the C++ and Python programming languages and use the mpi4py library (Dalcín, Paz, Storti, & D'Elía, 2008) to run on a computing cluster. The source code for the models can be downloaded from http://munk.cis.unimelb.edu.au/~stivalaa/community_diversity/.

Model 1: Extended Schelling model.

The first phase of the model described in Neal and Neal (2014) is based on the Schelling segregation model. Initially agents are assigned uniformly at random one of the two types, and placed randomly on the lattice. The diversity of an agent's neighborhood is measured as the fraction of that agent's neighboring agents which have a different type from the agent. The neighborhood here is defined as the eight lattice positions surrounding the agent, that is, the Moore neighborhood. A parameter of the model is the desired level of integration, σ, which is the fraction of neighbors that an agent requires to have the same type as itself. If $\sigma = 0$ then an agent does not care about the types of its neighbors; if $\sigma = 0.5$ then an agent requires at least 50% of its neighbors to have the same type.

The dynamics of the Schelling model are as follows. An agent is chosen randomly, and if the fraction of its neighboring agents that have the same type as itself is less than the threshold σ, then it moves to a random empty site on the lattice. This process is repeated until all agents are satisfied, that is, the fraction of neighboring agents that have the same type is at least σ.

The second phase of the model is the formation of a social network based on homophily and proximity. For all agents *i* and *j*, a tie X_{ij} is formed between *i* and *j* with probability (Neal & Neal, 2014):

$$\Pr(X_{ij} = 1) = \frac{\exp(\beta_0 + \beta_H \delta_{ij} + \beta_p d'_{ij})}{1 + \exp(\beta_0 + \beta_H \delta_{ij} + \beta_p d'_{ij})} \tag{1}$$

where $d'_{ij} = \dfrac{1}{1 + \exp \dfrac{d_{ij} - 5}{0.5}}$

in which d_{ij} is the Euclidean distance between agents *i* and *j* on the lattice and $\delta_{ij} = 1$ if agents *i* and *j* have the same type, else $\delta_{ij} = 0$. The parameter β_H controls the tendency towards homophily and β_p controls the tendency towards proximity, while $\beta_0 = -(\beta_H + \beta_p)$ sets the maximum probability of tie formation at 50%. We always use the parameters for the "typical set of behavioral tendencies" $\beta_H = 2.5$ and $\beta_p = 2.5$ (Neal & Neal, 2014, p. 5).

We extend this model to allow, instead of a single type which takes one of two values, a vector describing multiple uncorrelated dimensions of difference, as suggested by Neal and Neal (2014, p. 9). This is done by giving each agent, instead of a single binary variable representing its type, an F-dimensional vector describing its F features. Further, rather than each feature being binary, we allow it to take one of q different values. Note that this is the same as a culture vector in the Axelrod model; however, in this model, the features are immutable, and so we refer to it as a feature vector, rather than a culture vector.

Rather than being only the same or different, agents can now differ by degrees, by difference in none, some, or all of their features. This is exactly the cultural similarity in the Axelrod model of two agents i and j with culture vectors u and v respectively, which we measure using a normalized Hamming similarity

$$c_{ij} = \frac{1}{F}\sum_{l=1}^{F}\delta_{u_l v_l} \tag{2}$$

where $\delta_{u_l v_l} = 1$ when element l of vectors u and v is equal, and $\delta_{u_l v_l} = 0$ otherwise. Instead of counting the number of neighbors that have the same type (identical feature vectors) as the focal agent, we instead use the mean feature vector similarity $\bar{c}_i$ of the focal agent i with its neighbors, defined as

$$\bar{c}_i = \frac{1}{n_i}\sum_{k=1}^{n_i} c_{ik} \tag{3}$$

where the summation is over the n_i neighbors of agent *i*, and c_{ik} is defined by Equation (2). The threshold for an agent deciding to move is now no longer σ, but rather an intolerance threshold τ ($0 \le \tau \le 1$): an agent will move if $\bar{c}_i < \tau$, and the process continues until all agents have $\bar{c}_i \ge \tau$.

In the second phase, instead of Equation (1), the probability of a tie formation between two agents is

$$\Pr(X_{ij} = 1) = \frac{\exp(\beta_0 + \beta_H c_{ij} + \beta_p d'_{ij})}{1 + \exp(\beta_0 + \beta_H c_{ij} + \beta_p d'_{ij})} \qquad (4)$$

in which δ_{ij} has been replaced with c_{ij} so that tie formation depends on the degree of similarity between the two agents; they may be dissimilar on a feature and yet similar on others and so still have an increased likelihood of tie formation. Note that when $F = 1$, Equation (1) and Equation (4) are equivalent.

Depending on the number of agents and the values of τ, *F*, and *q*, it may be impossible for all agents to be satisfied, since there may be such a large number of different feature vectors that agents can never find a location with enough similar neighbors to satisfy their intolerance threshold τ. For this reason, the number of iterations is limited to 10^8. Runs where this limit is reached without the desired threshold of similar neighbors being reached are excluded from the results, since, as noted by Gauvin, Vannimenus, and Nadal (2009); Schelling (1969), the global utility can decrease, and not just increase, during the simulation. That is, when an agent changes location, it can happen that the gain in satisfaction for that agent can be less than the net loss in satisfaction for the neighbors of the old and new locations. Hence the measured diversity can be spurious if measured when the threshold is not globally satisfied.

Model 2: Extended Axelrod-Schelling model.

The extended Axelrod-Schelling model also consists of two phases. The first phase is similar to that described in Gracia-Lázaro et al. (2009), although we use the Moore (rather than the von Neumann) neighborhood and do not use periodic boundary conditions, so as to be consistent with Model 1. In addition, we introduce the concept of immutable (fixed) features in the feature vector. Let the number of immutable features be F_I, where $0 \le F_I \le F$. These F_I immutable features are used, just the same as the 1 - F_I mutable features, in measuring feature vector similarity with Equation (2), but are not affected by social influence, and so never change. Similarity is therefore computed on the basis of both the mutable (cultural) and immutable features in the feature vector.

Initially, agents are distributed randomly on the lattice and culture vectors are assigned uniform random values (no distinction is made between the mutable and immutable features here). At each step of the simulation, a random focal agent *i* is chosen, along with a random agent *j* in its neighborhood. The probability of a successful interaction between the two agents *i* and *j* is proportional to their feature vector similarity c_{ij} (Equation (2)). On a successful interaction where $c_{ij} < 1$, a mutable feature *l* such that $u_l \ne v_l$ (where *u* and *v* are the feature vectors for agents *i* and *j* respectively), if such a feature exists, is chosen at random and the assignment $u_l \leftarrow v_l$ is made so that the two agents become more culturally similar.

After each such step of the Axelrod dynamics, migration is incorporated according to the intolerance threshold τ ($0 \le \tau \le 1$), as in Model 1. If a successful interaction did not occur (no change to the feature vector was made) and $c_{ij} \ne 1$, then if $\bar{c}_{ij} < \tau$ the focal agent *i* moves to a random empty site on the lattice.

The simulation continues until an absorbing state is reached, in which no further interactions are possible. In this state, any two agents in the same Moore neighborhood have either identical mutable features, or completely distinct feature vectors (no features in common).

The second phase is the formation of the social network, identical to that used in Model 1 (Equation (4)).

If F = 1, F_I = 1, and q = 2, then the model is similar to the extended Schelling model, in that there is only one feature, which has only two possible values, and cannot change. As well as investigating the effect of increasing the number of features F, and traits q, we can vary the number of immutable features F_I, to investigate the effect of increasing or decreasing the number of features amenable to change by social influence By doing so we can investigate the hypothesis that by allowing homophily and social influence to operate on mutable features, the apparent incompatibility of diversity and high social network clustering can be overcome.

Measuring diversity and social network clustering.

The diversity of an agent's neighborhood is measured as the average feature vector distance between an agent and each of the agents in its Moore neighborhood $1-\bar{c}_i$ (where $\bar{c}_i$ is defined by Equation (3)). Note that diversity is computed on the basis of all attributes regardless of whether they are mutable or immutable. The overall level of diversity is then the mean of this value over all agents. When F = 1 this is equivalent to the neighborhood diversity measurement used by Neal and Neal (2014).

Triadic closure in the social network is measured by the global clustering coefficient. This is the ratio of the number of closed triplets to the number of connected triplets ("two-stars", S_2) of nodes in the graph, or equivalently (since a triangle consists of three closed triplets), $\frac{3T}{S_2}$ where T is the number of triangles (Newman, Strogatz, & Watts, 2001).

Figure 1 illustrates an example of the operation of Model 2, with five features of which only one is immutable, and features having 20 possible values. Figures 1A and 1B show the initial (random) state of the model, with Figure 1A showing the values of the immutable feature. Figure 1B shows the initial state with the agents colored differently according to each unique configuration of all four mutable features. Figure 1C and Figure 1D show the agents' immutable and mutable attributes at the absorbing state. Figure 1C shows the agents with colors according to the single immutable feature. The neighborhood is still quite diverse with respect to the immutable feature. Figure 1D shows the agents colored according to the configurations of the four mutable features. The social influence process has produced fewer remaining distinct cultures, and the neighborhood is now quite segregated with respect to these cultures. As a result the overall level of local diversity is low and the clustering coefficient of the social network (not shown) is high. This case illustrates how the processes of homophily and social influence have resulted in a society that retains cultural diversity at the global level (i.e., multiple cultures coexist in society, rather than a single overarching monoculture) and a neighborhood that is relatively segregated according to cultural attributes (for example, music taste and clothing preference), while at the same time being integrated with respect to an immutable attribute, such as race. Social networks formed with tendencies towards homophily and proximity then allow this neighborhood to have a strong sense of community as measured by clustering despite the high level of diversity on the immutable attribute (e.g. race).

Results

We ran both models with N = 500 agents on a square lattice with dimension L = 25, giving a population density of N/L^2 = .8, comparable to that used in Neal and Neal (2014), and varied the intolerance threshold τ from zero to one in 100 equally spaced steps. Each model was run 50 times from the same random initialization. This process was repeated for different values of *F* and *q*, and, for the extended Axelrod-Schelling model, different values of F_I.

Model 1: Extended Schelling model with mean similarity.

Figure 2 shows the results for Model 1, a variation of the Neal and Neal (2014) model in which the migration is based on an intolerance threshold τ on the mean feature vector similarity of an agent's neighbors, rather than the number of identical neighbors. There are missing data points for higher values of τ for sufficiently large values of *F* and *q*, since for these values the desired level of mean similarity cannot be achieved, so the data is excluded from the results.

The top left graph ($F = 1$, $q = 2$) of Figure 2 reproduces the Neal and Neal (2014) results, where there is only one feature which can take one of two values. For larger values of *q* and *F*, higher levels of neighborhood diversity exist, since there is a larger scope of cultural possibilities. For larger values of *q*, the strong negative correlation between diversity and the clustering coefficient continues to hold. It also holds just as strongly for larger values of *F*, which represent multiple independent features. This is contrary to the hypothesis of Neal and Neal (2014, p. 9), based on Blau (1977), that additional uncorrelated dimensions would mitigate this main finding of a negative correlation due to "intersecting parameters promot[ing] intergroup relations" (Blau, 1977, p. 45).

Model 2: Extended Axelrod-Schelling model.

Figure 3 shows the relation between diversity and sense of community as measured by clustering for Model 2, the Axelrod-Schelling model, for $F = 5$ and with the number of immutable features F_I ranging from 0 to 5, and selected values of *q*. When $F_I = 0$ (left column of graphs), there are no immutable features so the model reduces to the Axelrod model when $\tau = 0$, and the Axelrod-Schelling model of Gracia-Lázaro et al. (2009) for other values of τ. Here, a monocultural absorbing state results for small values of q ($q \leq 10$ in Figure 3), so the level of diversity is zero. As the number of immutable features increases, the maximum level of neighborhood diversity at the absorbing state can also increase, since the immutable features guarantee that a level of diversity remains in the population. When all features are immutable, $F_I = F = 5$, the model is more similar to the Schelling model.

Figure 3 shows three patterns of diversity-clustering relations. In most cases shown (Class 1), diversity and sense of community cannot coexist, with the diversity-clustering relation showing an approximately convex decreasing curve, with a negative correlation, not dissimilar to those in Figure 2. However in some cases (Class 2), the diversity-clustering relation is closer to concave, particularly, when F_I is small and q is large (e.g., $F_I = 1$ and $q = 100$). Here, the overall correlation is still negative. Furthermore, there are cases (Class 3) where the correlation is nonsignificant or even positive overall if $F_I = 0$ and q is small enough (for example $F_I = 0$ and q ≤ 75), or $F_I = 1$ and q is in a certain range of values (for example $F_I = 1$ and $q = 30$). Classes 2 and 3 present counterexamples to the view that diversity undermines sense of community.

First, let us investigate Class 3. Figure 4 plots the normalized (by division by N) mean size of the largest region on the lattice occupied by agents with the same feature vector, a quantity often used as the order parameter of the Axelrod model (Castellano, Marsili, & Vespignani, 2000; Gracia-Lázaro et al., 2009; Konstantin Klemm, Victor M. Eguíluz, Raúl Toral, & Maxi San Miguel, 2003), which separates the two phases of the model's absorbing state. In the Axelrod model, the first phase is the ordered state, where there is only one region or one dominant region that occupies most of the lattice; and the second phase is the disordered state, where the population of agents fragments into many small regions. The phase transition occurs at a critical value of q, where the variance of the order parameter is at its maximum. For

Class 3 with $F_I = 0$ and small values of q, Figure 4 shows that the system is largely monoregional, and hence, on average, nearly zero diversity exists. This is the case where diversity positively, albeit weakly, correlates with clustering. Although diversity and sense of community can coexist here, the level of diversity is very low and the diversity-community dialectic would not be a major issue in this class of situations. When $F_I = 0$ we can see that the phase transition occurs for $\tau \leq .2$, but for higher values of τ it no longer occurs and an ordered, largely monoregional state prevails for all values of q. Hence the diversity apparent in Figure 3 for $F_I = 0$ for large enough q (≥ 30) arises from these low values of τ only.

Cases in Class 3 (an insignificant or even positive correlation) can also occur when $F_I = 1$, for certain values of q (e.g. $q = 30$). From Figure 4 we can see that, when $F_I = 1$, large regions exist only for very small values of q, and for the values of q when Class 3 occurs for $F_I = 1$, the largest region size is small. (Note that the regions here are those in which all agents have the same feature vector, including both the immutable and mutable attributes). This case is of more interest as a model of real-word scenarios, since it allows for an immutable attribute, and high levels of diversity can exist, at least for small values of the intolerance threshold τ (i.e., when agents are tolerant towards diversity).

Let us now investigate the cases in Class 2 where F_I is small and q is large. Recall that these cases showed non-monotonic diversity-clustering relations. Figure 5 shows the number of unique feature vectors (normalized by division by N) remaining at the absorbing state. Note that for $F_I = F = 5$ the level of diversity never changes: the number of feature vectors is small for small q because there are only few possible feature vectors. E.g. if $q = 2$ then there are only $q^F = 2^5 = 32$ possible feature vectors. When these are assigned uniformly at random to $N = 500$ agents, the normalized number of cultures is .064. When $q^F > N$ then the normalized number of cultures will be 1.0 since it becomes increasingly unlikely that assigning feature vectors at random will result in fewer than N distinct vectors. Hence the case of $F_I = F$ where all the features are immutable preserves exactly the diversity at the initial conditions, while $F_I = 0$ is the Axelrod model, where the phase transition is controlled by the value of q. When F_I is increased, that is, when one or two features are made immutable, a level of diversity within the system increases as q increases, particularly for small values of the intolerance threshold τ (i.e., when agents are tolerant towards diversity).

Discussion

By extending the model of Neal and Neal (2014) with additional independent features, we find that, contrary to the hypothesis of Neal and Neal (2014, p. 9), their main finding of an incompatibility of diversity with “sense of community” (high clustering coefficient in the modeled social network) is not mitigated by additional uncorrelated features. In terms of community psychology, Neal and Neal (2014, p. 9), in discussing the simplifications inherent in their model, suggest that perhaps the most serious simplification is the use of only a single feature (for example, race), neglecting the existence of potentially many simultaneous statuses and identities, which may be correlated or not. We have explored the consequences of partly removing this simplification, allowing multiple uncorrelated dimensions of difference (for example gender, as well as race), and find that it does not mitigate the original finding of Neal and Neal (2014) of the incompatibility of diversity and sense of community, in their original setting of having immutable attributes only.

Nevertheless, when some of the agent attributes are allowed to change due to social influence, the conclusion that diversity and sense of community are always incompatible no longer holds. We constructed an Axelrod-Schelling model (Gracia-Lázaro et al., 2009) with the addition of the “interaction” (social network formation) phase of Neal and Neal (2014) to measure social network clustering. We extended the model by having both mutable and immutable features, which allow features that are subject to social influence (such as tastes, or opinions) in the Axelrod model dynamics to co-exist with features which do not change (for example, race), such as those used in the Schelling model of residential segregation. Using this model we find situations in which the presence of the mutable features (those amenable to social influence in the Axelrod model dynamics) can result in the relationship between diversity and clustering coefficient no longer being monotonic, but instead having a peak in the clustering coefficient at an intermediate (but still low) value of diversity. These situations only occur with a small number (zero or one, or, to a lesser extent, two) of immutable features. When there are no immutable features, the model is purely a model of cultural diffusion, with agents having no features, such as, for example, race, that are not subject to change via social influence. This case has no real world application when considering multiracial communities. However the case where there is a single immutable feature can be considered applicable to a multiracial community (the single immutable attribute representing race). In such a case the model shows that it is possible that diversity and community do not have a simple negative correlation, but rather the clustering coefficient (representing sense of community) has a global maximum value not at the lowest level of neighborhood diversity, but at an intermediate (but still quite low) value of diversity.

This would seem to imply that, in such situations, the sense of community is maximized when the level of neighborhood diversity is nonzero, but still low. While this is more hopeful for the values of community psychology than the simple negative correlation between community and diversity described by Neal and Neal (2014), it would still seem to imply that it might be difficult, if not impossible, to achieve a strong sense of community with a very high level of neighborhood diversity. However, this is not to say that we ought to try to maximize the sense of community in a neighborhood by attempting to ensure that the level of neighborhood diversity is not “too high”. As discussed in Townley et al. (2011), there is a dialectic between these two aspects of community psychology, and we should try to achieve some reasonable balance between the two, rather than trying to “maximize” one aspect, possibly at the expense of the other.

In common with the models on which this work is based, we have made a number of simplifying assumptions which ignore the complexities of reality. Most notably, the models assume that the cultural attributes (both immutable and mutable) are independent, and that all such attributes are meaningfully measured by a discrete value (with the same number of possible values for each feature). Even with these caveats however, we can suppose that a situation in which these findings apply is a neighborhood which is diverse with respect to a single immutable characteristic (for example, race), there is a large scope of cultural possibilities, which is to say a range of cultural attributes subject to social influence with a large number of possible traits, and has a relatively low level of intolerance. With respect to the first and third conditions (diversity on an immutable attribute and relatively low intolerance), a realistic situation in which this might apply would be a relatively racially integrated neighborhood: the original Schelling model would after all imply that low intolerance is a necessary condition for diversity. With respect to the second condition, a large scope of cultural possibilities, this is in many ways as much an aspect of how we model culture as it is of anything inherent in “culture” or people themselves, however it is certainly not unrealistic for some cultural attributes, such as language, to have a large number of possibilities. For example, it is contended that 300 languages are spoken in London

(Vertovec, 2007, p. 1032), although it is of course unlikely that nearly so many would exist in a single neighborhood.

This possibility that diversity and sense of community can co-exist seems hopeful for the values of community psychology. However, that they are not necessarily positively correlated either is problematic: we cannot assume that efforts to foster respect for diversity will necessarily also encourage a sense of community. Indeed, both sides of the community-diversity dialectic must be addressed (Townley et al., 2011). Practically speaking, how might this be done? Townley et al. (2011, pp. 80-81) suggest such measures as block parties and cross-cultural workshops, noting that such interventions must involve sustained positive and intentional contact between disparate groups in order to foster a sense of community. But can such interventions simultaneously encourage a respect for diversity?

As noted by Neal and Neal (2014, p. 2), the contact hypothesis (that social contact between diverse groups can reduce prejudice) has spawned a vast literature, with apparently inconsistent conclusions, but contact must at least be a necessary condition of promoting respect for diversity. An exhaustive meta-analysis of the contact hypothesis literature (Pettigrew & Tropp, 2006) is encouraging in this respect: intergroup contact typically reduces prejudice, and Allport’s (Allport, 1954) conditions (equal status, common goals, intergroup cooperation, and authority sanction) facilitate this reduction in prejudice, but are not necessary conditions (Pettigrew, Tropp, Wagner, & Christ, 2011). This is further encouragement for the “ecological pragmatism” approach of Kelly, Azelton, Burzette, and Mock (1994), briefly described by Townley et al. (2011, p. 81), of, rather than focusing on an individual level, creating social settings that enhance the appreciation of diversity. An example of a process that might facilitate this is “boundary spanning”, described by Kelly et al. (1994, p. 438) as “the actions of people who engage in tasks at one setting while simultaneously relating to people in other settings." They give as an example foreign exchange students, who are from different cultures, but have in common other attributes (age, educational level), and are therefore able to use these common attributes to overcome the initial barriers of cultural difference, with the expected benefit that both groups will gain a greater appreciation of diversity (Kelly et al., 1994, pp. 438-439).This conception of boundary spanning is applicable to the interpretation of the results of our model. The mutable features, representing cultural attributes such as political opinions, or taste in music, which are amenable to a process of social influence, can, if they become sufficiently aligned, be used to overcome barriers of difference on immutable attributes, such as race.

A more concrete specific example of how interventions might be designed to increase sense of community and respect for diversity simultaneously is a music therapy project described by Gilboa, Yehuda, and Amir (2009) in which a multicultural group met in weekly sessions, over an extended period, for musical presentations and discussion under the supervision of a music therapist. It was found that, following the sessions, participants expressed more acceptance and openness towards the "other", and collective self-esteem was higher regarding both adopted (Israeli) culture and the immigrants' culture of origin. It seems clear that this project successfully increased respect for diversity in the group. Further, qualitative results indicate that the project helped people to develop relations outside the classroom, make new acquaintances, and improve the group atmosphere (Gilboa et al., 2009, p. 18), hopeful signs for an improved sense of community, although no quantitative measure was made of this concept. Musical taste is an almost canonical example of the kind of mutable cultural attribute we have been considering, so the results of this study are highly relevant. Intriguingly, it was found that there was no significant change in participants' attitudes towards quality, likeability, or perceived familiarity with the music of various cultures presented following the study, however there was a significant increase in the number of musical excerpts that participants classified as “music” in comparison to the attitudes prior to the study (Gilboa et al., 2009, p. 21). We can interpret this as a process of social influence that has resulted in a set of cultural attributes as to what (for each type of music) is, or is not, perceived as “music”, becoming more similar among the participants (despite other cultural attributes such as likability and quality of each musical type not changing significantly).

A potential problem with any shared group identity is that more powerful or influential people in the group have a stronger role in forming the group identity, which then reflects the ideals of the dominant culture, causing individuals to lose aspects of their identity (Townley et al., 2011). This problem can be conceptualized in terms of “macrobelonging”, the shared identity by virtue of group membership, and “microbelongings”, the unique elements of culture retained by individuals (Wiesenfeld, 1996). We have not explored concepts of social power or inequalities of influence or group size. In the Neal and Neal (2014) model, as in the original Schelling model, the two groups are of equal size, and in our models, the attributes (both mutable and immutable) are uniformly randomly distributed among the population, as is traditionally the case in Axelrod type models. In all cases, all agents are equally susceptible to social influence: there is no concept of some agents having more social power or being more influential than others. Some recent work has started to explore the consequences of different distributions of culture vectors in Axelrod type models (Babeanu, Talman, & Garlaschelli, 2015; Stivala, Robins, Kashima, & Kirley, 2014; Valori, Picciolo, Allansdottir, & Garlaschelli, 2012), and Crooks (2010) briefly explores the consequence of unequal population sizes in a residential segregation model, but this is an area requiring further research.

All in all, the findings suggest that human diversity does not have to undermine the sense of community as indicated by network closure. Even if there are diverse categories of people with such diverse immutable characteristics as race, ethnicity, and the like, as long as there is a sufficient variety of possible *mutable* features that they can adopt and share, the combination of homophily and social influence can create a social ecology in which both diversity and sense of community can flourish in the long run. It is however important to note that this conclusion rests on three preconditions. First of all, there must be sufficient tolerance in the populace for social interaction to take place between agents with different immutable features such as race. Second, there must be sufficient diversity in mutable features such as cultural values and beliefs (i.e., a large enough scope of cultural possibilities). Third, there must be sufficiently long period of time in which social interactions can continue and social influence can have its effects on mutable features in order for a degree of cultural convergence to occur. As many societies become "super-diverse" (Vertovec, 2007), where metaphorically speaking people with backgrounds of all nationalities in the world can potentially live in a single city, the reconciliation of human diversity and sense of community is an issue of critical importance (e.g., Putnam, 2007). What we have shown here is that, even if homophily is a significant force for relationship formation, culturally based similarity can help to build a sense of community in diverse neighborhoods.

References

Allport, G. W. (1954). The nature of prejudice. Cambridge, MA: Perseus Books.

Axelrod, R. (1997). The dissemination of culture: A model with local convergence and global polarization. *Journal of Conflict Resolution, 41*, 203-226.

Babeanu, A.-I., Talman, L., & Garlaschelli, D. (2015). Structural properties of realistic cultural space distributions. *arXiv preprint arXiv:1506.01634*.

Blau, P. M. (1977). A macrosociological theory of social structure. *American Journal of Sociology, 83*(1), 26-54.

Castellano, C., Marsili, M., & Vespignani, A. (2000). Nonequilibrium phase transition in a model for social influence. *Physical Review Letters, 85*(16), 3536-3539.

Centola, D., González-Avella, J. C., Eguíluz, V. M., & San Miguel, M. (2007). Homophily, cultural drift, and the co-evolution of cultural groups. *Journal of Conflict Resolution, 51*(6), 905-929.

Coleman, J. S. (1988). Social capital in the creation of human capital. *American Journal of Sociology, 94*, S94-S120.

Conte, R., Gilbert, N., Bonelli, G., Cioffi-Revilla, C., Deffuant, G., Kertesz, J., . . . Helbing, D. (2012). Manifesto of computational social science. *European Physical Journal Special Topics, 214*, 325-346.

Crooks, A. T. (2010). Constructing and implementing an agent-based model of residential segregation through vector GIS. *International Journal of Geographical Information Science, 24*(5), 661-675.

Dalcín, L., Paz, R., Storti, M., & D'Elía, J. (2008). MPI for Python: Performance improvements and MPI-2 extensions. *Journal of Parallel and Distributed Computing, 68*(5), 655-662.

Gauvin, L., Vannimenus, J., & Nadal, J.-P. (2009). Phase diagram of a Schelling segregation model. *European Physical Journal B, 70*(2), 293-304.

Gilboa, A., Yehuda, N., & Amir, D. (2009). Let's talk music: A musical-communal project for enhancing communication among students of multi-cultural origin. *Nordic Journal of Music Therapy, 18*(1), 3-31.

Gracia-Lázaro, C., Floría, L. M., & Moreno, Y. (2011). Selective advantage of tolerant cultural traits in the Axelrod-Schelling model. *Physical Review E, 83*, 056103.

Gracia-Lázaro, C., Lafuerza, L. F., Floría, L. M., & Moreno, Y. (2009). Residential segregation and cultural dissemination: An Axelrod-Schelling model. *Physical Review E, 80*(4), 046123.

Gracia-Lázaro, C., Quijandría, F., Hernández, L., Floría, L. M., & Moreno, Y. (2011). Coevolutionary network approach to cultural dynamics controlled by intolerance. *Physical Review E, 84*(6), 067101.

Guerra, B., Poncela, J., Gómez-Gardeñes, J., Latora, V., & Moreno, Y. (2010). Dynamical organization towards consensus in the Axelrod model on complex networks. *Physical Review E, 81*(5), 056105.

Heider, F. (1958). *The psychology of interpersonal relations*. Hillsdale, NJ: Erlbaum.

Kelly, J. G., Azelton, L. S., Burzette, R. G., & Mock, L. O. (1994). Creating social settings for diversity: An ecological thesis. In E. J. Trickett, R. J. Watts & D. Birman (Eds.), *Human diversity: Perspectives on people in context* (pp. 424-451). San Francisco, CA, US: Jossey-Bass.

Klemm, K., Eguíluz, V. M., Toral, R., & San Miguel, M. (2003). Global culture: A noise-induced transition in finite systems. *Physical Review E, 67*(4), 045101(R).

Klemm, K., Eguíluz, V. M., Toral, R., & San Miguel, M. (2003). Nonequilibrium transitions in complex networks: A model of social interaction. *Physical Review E, 67*(2), 026120.

Macy, M., & Willer, R. (2002). From factors to actors: Computational sociology and agent-based modeling. *Annual Review of Sociology, 28*, 143-166.

McPherson, M., Smith-Lovin, L., & Cook, J. M. (2001). Birds of a feather: Homophily in social networks. *Annual Review of Sociology, 27*, 415-444.

Neal, Z. (2015). Making big communities small: Using network science to understand the ecological and behavioral requirements for community social capital. *American Journal of Community Psychology, 55*(3-4), 369-380.

Neal, Z., & Neal, J. W. (2014). The (in)compatibility of diversity and sense of community. *American Journal of Community Psychology*, *53*(1-2), 1-12.

Newman, M. E., Strogatz, S. H., & Watts, D. J. (2001). Random graphs with arbitrary degree distributions and their applications. *Physical Review E*, *64*(2), 026118.

Pettigrew, T. F., & Tropp, L. R. (2006). A meta-analytic test of intergroup contact theory. *Journal of Personality and Social Psychology, 90*(5), 751-783.

Pettigrew, T. F., Tropp, L. R., Wagner, U., & Christ, O. (2011). Recent advances in intergroup contact theory. *International Journal of Intercultural Relations*, *35*(3), 271-280.

Pfau, J., Kirley, M., & Kashima, Y. (2013). The co-evolution of cultures, social network communities, and agent locations in an extension of Axelrod's model of cultural dissemination. *Physica A*, *392*(2), 381-391.

Putnam, R. D. (2007). E pluribus unum: Diversity and community in the twenty-first century: The 2006 Johan Skytte prize lecture. *Scandinavian Political Studies*, *30*(2), 137-174.

Schelling, T. C. (1969). Models of segregation. *American Economic Review, 59*(2), 488-493.

Schelling, T. C. (1971). Dynamic models of segregation. *Journal of Mathematical Sociology*, *1*(2), 143-186.

Stivala, A., Robins, G., Kashima, Y., & Kirley, M. (2014). Ultrametric distribution of culture vectors in an extended Axelrod model of cultural dissemination. *Scientific Reports, 4*, 4870.

Townley, G., Kloos, B., Green, E. P., & Franco, M. M. (2011). Reconcilable differences? Human diversity, cultural relativity, and sense of community. *American Journal of Community Psychology, 47*(1-2), 69-85.

Valori, L., Picciolo, F., Allansdottir, A., & Garlaschelli, D. (2012). Reconciling long-term cultural diversity and short-term collective social behavior. *Proceedings of the National Academy of Sciences of the USA, 109*(4), 1068-1073.

Vazquez, F., González-Avella, J. C., Eguíluz, V. M., & San Miguel, M. (2007). Time-scale competition leading to fragmentation and recombination transitions in the coevolution of network and states. *Physical Review E, 76*(4), 046120.

Vertovec, S. (2007). Super-diversity and its implications. *Ethnic and Racial Studies, 30*(6), 1024-1054.

Wiesenfeld, E. (1996). The concept of “we”: A community social psychology myth? *Journal of Community Psychology, 24*(4), 337-346.

Xiao, X. H., Ye, G. W., Wang, B., & He, M. F. (2009). Cultural dissemination in a complex network. *Physica A, 388*, 775-779.

Figure Captions

1. Example states of Model 2 (N = 500, q = 20, F = 5, F_I = 1, τ = .06). (A) Initial state of the model with colors according to the immutable feature. (B) Initial state of the model with colors according to the mutable features. (C) Absorbing state of the model with colors according to the immutable feature: there is a high level of diversity on this feature (the neighborhood is quite integrated). (D) Absorbing state of the model; the number of different cultures remaining is quite small and the neighborhood is quite segregated with respect to these cultures. As a result, the overall diversity measured over all features is quite low and the clustering coefficient is quite high.

2. Global clustering coefficient and neighborhood diversity for Model 1, the Neal and Neal (2014) model (F = 1, q = 2), as well for extensions to multiple independent features (F > 1) and more than two types for each feature (q > 2), where the threshold is on mean cultural similarity of neighbors, not the number of identical neighbors. Each plot shows the Spearman rank correlation coefficient ρ between the diversity and clustering coefficient. The value of the mean neighborhood cultural similarity intolerance threshold is τ.

3. Global clustering coefficient and neighborhood diversity for Model 2, the Axelrod-Schelling model. Each plot shows the Spearman rank correlation coefficient ρ between the diversity and clustering coefficient at the absorbing state of the model. The value of the mean neighborhood cultural similarity intolerance threshold is τ. The data points are

shown with transparency to help make overlapping points visible, and are colored according to values of τ in buckets according to the fraction of immutable attributes (F_I / F) they represent.

4. Normalized size of the largest cultural region plotted against q for different numbers of immutable features F_I and different values of the intolerance threshold τ. Error bars represent one standard deviation.

5. Number of distinct feature vectors remaining at the absorbing state plotted against q for different numbers of immutable features F_I and different values of the intolerance threshold τ. Error bars represent one standard deviation.

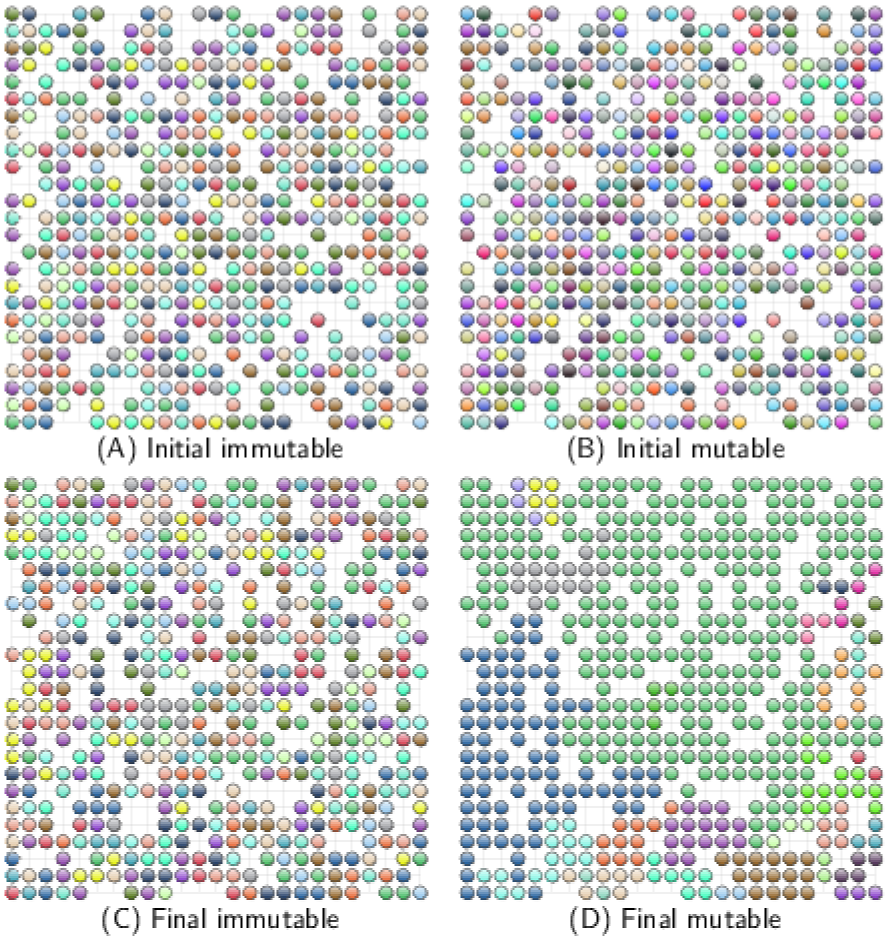
(A) Initial immutable
(B) Initial mutable
(C) Final immutable
(D) Final mutable

Figure 1

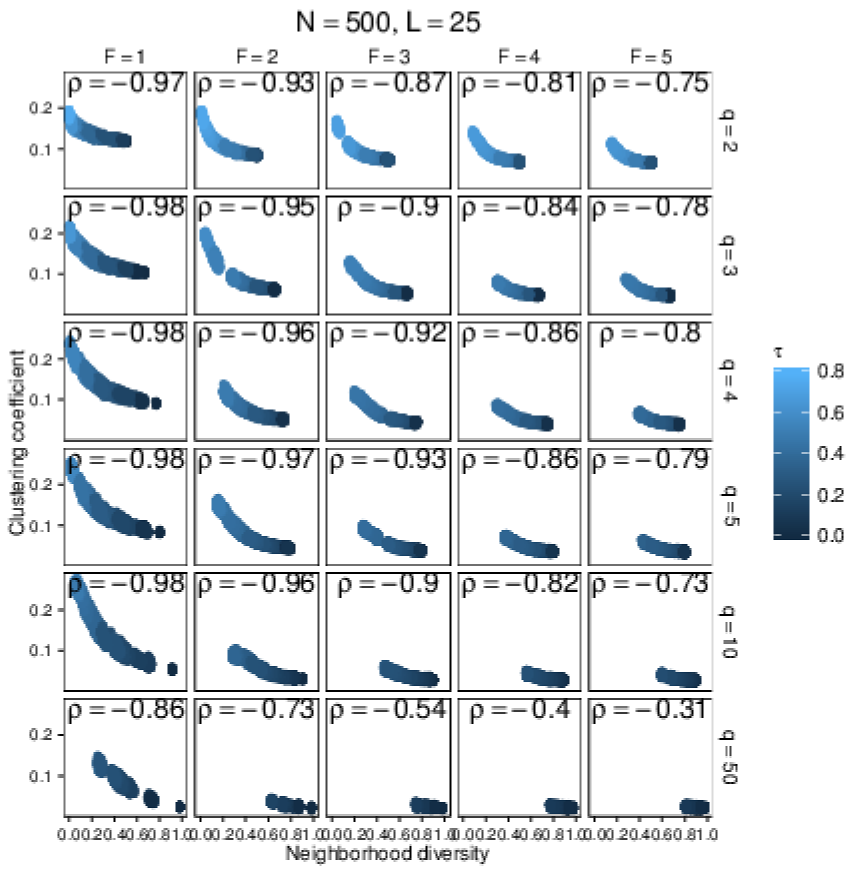
N = 500, L = 25
F = 1
F = 2
F = 3
F = 4
F = 5
q = 2
q = 3
q = 4
q = 5
q = 10
q = 50
ρ = −0.97
ρ = −0.93
ρ = −0.87
ρ = −0.81
ρ = −0.75
ρ = −0.98
ρ = −0.95
ρ = −0.9
ρ = −0.84
ρ = −0.78
ρ = −0.98
ρ = −0.96
ρ = −0.92
ρ = −0.86
ρ = −0.8
ρ = −0.98
ρ = −0.97
ρ = −0.93
ρ = −0.86
ρ = −0.79
ρ = −0.98
ρ = −0.96
ρ = −0.9
ρ = −0.82
ρ = −0.73
ρ = −0.86
ρ = −0.73
ρ = −0.54
ρ = −0.4
ρ = −0.31
Clustering coefficient
Neighborhood diversity
ε
0.8
0.6
0.4
0.2
0.0

Figure 2

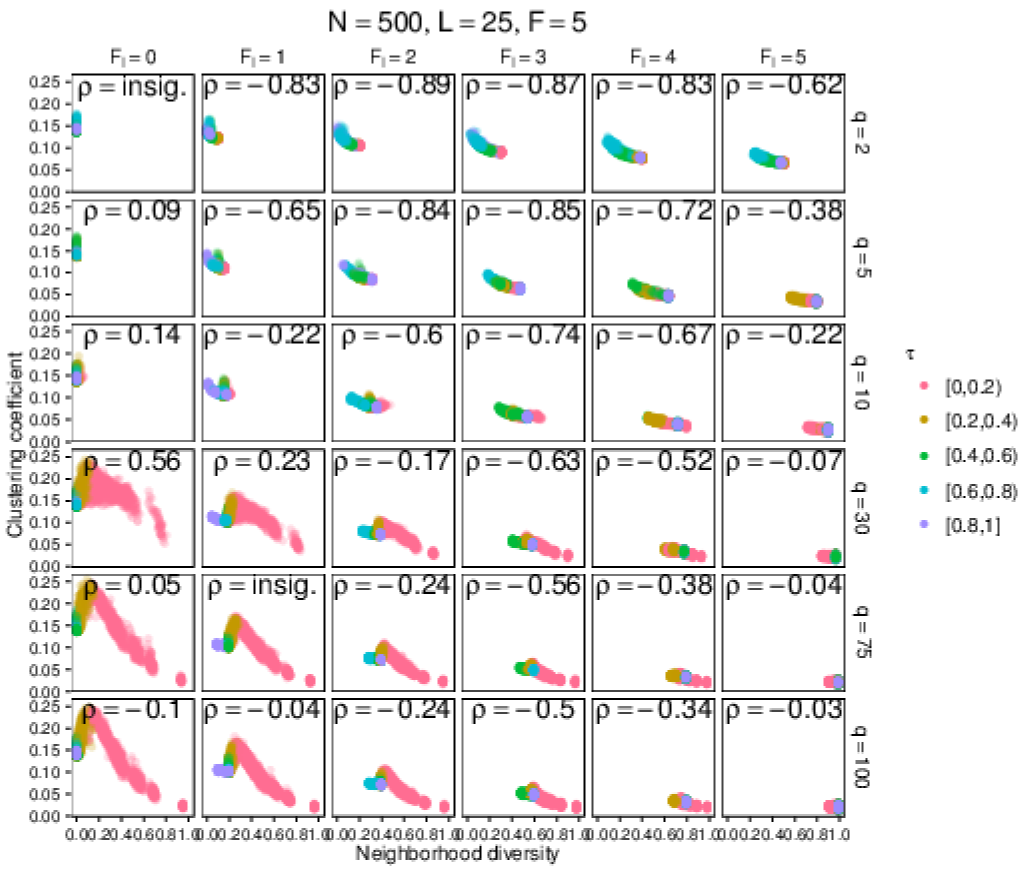
N = 500, L = 25, F = 5
Clustering coefficient
Neighborhood diversity
τ
[0,0.2)
[0.2,0.4)
[0.4,0.6)
[0.6,0.8)
[0.8,1]

Figure 3

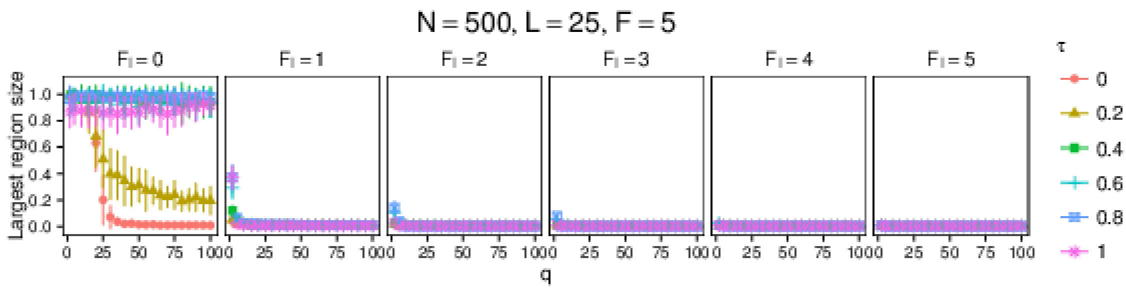
N = 500, L = 25, F = 5
F_l = 0
F_l = 1
F_l = 2
F_l = 3
F_l = 4
F_l = 5
Largest region size
q
τ
0
0.2
0.4
0.6
0.8
1

Figure 4

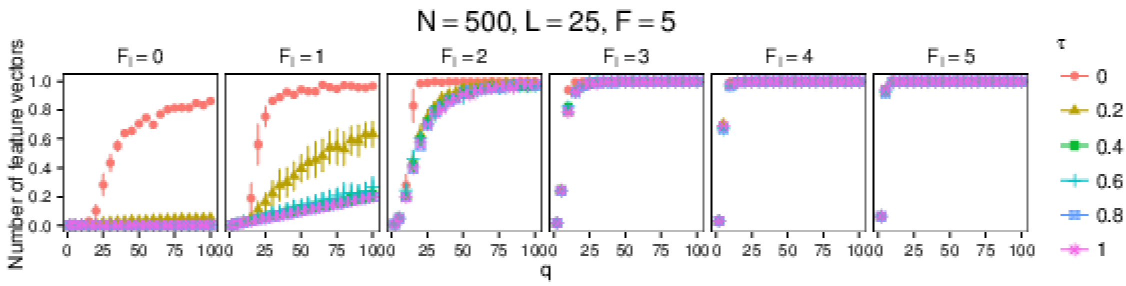
N = 500, L = 25, F = 5
$F_I = 0$
$F_I = 1$
$F_I = 2$
$F_I = 3$
$F_I = 4$
$F_I = 5$
Number of feature vectors
q
τ
0
0.2
0.4
0.6
0.8
1

Figure 5