Homophily and competition: a model of group affiliation

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Abstract. How can we understand the interaction between the social network topology of a population and the patterns of group affiliation in that population? Each aspect influences the other: social networks provide the conduits via which groups recruit new members, and groups provide the context in which new social ties are formed. While many social simulation models exhibit group formation as a part of their behaviour (*e.g.*, opinion clusters or converged cultures), models that explicitly focus on group affiliation are rare. We introduce one such model, based upon the ecological theory of group affiliation, and use it to explore the effect of two system properties—bias toward the creation of homophilous ties and competition between groups—on the dynamics of social evolution and group formation.

1 Introduction

Groups are an important social phenomenon, representing an intermediate level of organisation between individuals and society as a whole. Many types of groups exist, including family, professional, recreational, social, political and charities. The individuals associated with these groups may be distinguished by such demographic variables as their sex, age, race, profession and educational background. Some of these groups (*e.g.*, religious or political groups) may be exclusive, in that membership in one group precludes membership in other groups of that type, while others are non-exclusive: a single individual may be a member of multiple recreational or voluntary groups, for example. The pattern of groups in a social network may therefore be fuzzy, with indistinct boundaries. One general constraint on group membership is that affiliation with a group tends to involve the commitment of time and energy to events associated with that group (*e.g.*, meetings, fund-raising, or engaging in social activities) [1]. Therefore, there is a limit on the number of groups with which a single individual may be actively involved. As a result, groups must compete with one another for the time and resources of their potential members [2].

The dynamics of groups are an emergent property of decisions made by individuals about both their affiliations and their social contacts. Social groups and social networks share a reflexive relationship: Groups grow via the recruitment of new members through existing social contacts [3]. At the same time, groups act as a foci for the formation of new social ties, as group activities bring previously unknown people into contact [4]. Individuals may leave groups as a result of demands on their time by competing groups, a waning interest in the group's purpose, or pressure from social contacts who are not group members.

A second important factor in the dynamics of groups is homophily – the principle that "like attracts like". Given a choice, people are widely observed to preferentially interact with others with whom they share similar characteristics [5]. When most network ties are between similar individuals, and most group recruitment occurs via network ties, the result is homogeneous groups. It has been suggested that the observed homogeneity of social groups can have negative consequences at both a societal level and a group level. Homophily can lead to segregation within societies, with a negative impact on social integration. It has been argued that voluntary organisations should act as "perfect arenas for such integration" by bringing together individuals of disparate social backgrounds according to shared interests or goals [6]. However, studies reveal that such organisations tend to be homogeneous, either through choice (dissimilar individuals tend to leave at higher rates), or influence (individuals who spend time together come to share similar views [5]. Furthermore, homogeneity within groups can be harmful to the interests of the groups: observations of social movements indicate that a movement's efficacy (it's ability to achieve its aims) is dependent on the diverse skills and resources that its members can call upon. Such skills and resources are likely to be maximised among heterogeneous groups [7].

There are several reasons then to be interested in the dynamics of groups: An understanding of group level processes, and how they emerge from and influence the behaviour of individuals, is a critical part of understanding social order. Is it possible to predict or explain the success or failure of groups formed with a particular social or political agenda? How do organisations adapt and change to changing environmental conditions? How can such an understanding inform strategies of groups seeking to survive and thrive in a complex environment?

Despite the presence of group level behaviour in a number of different categories of social simulation model, there are few models explicitly of the dynamics of group affiliation and social structure evolve. In this paper, we present one such model, based upon McPherson's ecological theory of group affiliation [2, 8, 9].

2 Background

2.1 Theoretical basis

Voluntary associations: While social groups can take a broad range of forms, such as families, peer groups, workplaces, etc., particular attention has been paid to voluntary associations as these types of organisation are freely joined and left by individuals, without little influence from government or market forces.

The significance of voluntary associations for societal integration has a long history [10]. One strand of theory runs that voluntary associations have the potential to act as bridges across demographic categories by providing opportunities for interaction that would otherwise be absent [11]). Thus, they play a role in reducing societal cleavages that may result in conflict or inequality. However, another perspective is that, as such association tend to be homogeneous, they actually reinforce existing societal divisions [6]. One approach to resolving this apparent contradiction is to distinguish between different types of voluntary association [12]. Glanville distinguishes on the basis of association location (internal or external to an individual's neighbourhood), purpose (expressive or instrumental) and individual gender, and looks at their effect on homophily along several sociodemographic dimensions, concluding that, although different types of voluntary associations have diverse effects, their general tendency is to reinforce homophily rather than diversity.

While a large body of literature exists on voluntary associations, here we briefly review those studies that have informed the development of our model. We are primarily interested in the conditions under which individuals join and leave groups [1], and the influence that group membership has on the formation of social ties. One possibility is that individuals make independent decisions about their affiliation, on the basis of their personal beliefs and values. It is widely accepted however, that an individual's social context plays an important (perhaps dominating) role [3, 13, 14].

- McAdam and Paulsen [13] emphasise that social ties to existing members of an organisation (here social movements) are the strongest predictor of future recruitment. They also distinguish between different types of social ties, some of which may be negative as well as positive.
- McPherson et al. [15] 1992 analyse how network ties influence the rate at which individuals join and leave voluntary associations: ties between group members increase the duration of membership (*i.e.*, decrease the rate of leaving), while ties to individuals external to the group decrease the duration of membership. They also find that the effect of additional neighbours is cumulative.[1]
- Sandell [16] provides evidence of the influence of negative ties, demonstrating how contact with ex-members of an organisation can decrease the likelihood of joining, and increase the likelihood of leaving the organisation.
- Snow et al. [3] discuss the fact that the time and resources of group members are limited, and therefore individuals with multiple memberships are more likely to leave an organisation than those with fewer memberships.
- Finally, Feld [4] argues for the importance of social groups as foci for the generation of new social ties.

Sociodemographic space and the ecological theory of group affiliation: The basic premise of the organisational ecology is that organisations exist within a broader community context, and that they are defined by the individuals of which they are composed, other organisations in their community, and environmental factors [17]. The ecological theory of group affiliation developed by McPherson and

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[1] They also distinguish between strong and weak ties, which, currently, our model does not.

colleagues, suggests specifically that because individuals are limited in time and resources, organisations must “compete” for them [2, 8, 9].

A key element of McPherson’s ecology theory of group affiliation is Blau space: “the k-dimensional system generated by regarding the sociodemographic variables as dimensions” [15]. Each individual occupies a position in Blau space, defined by sociodemographic dimensions such as geographic location, age, sex, etc. Multiple individuals may occupy the same location. The dimensions of Blau space are features that change relatively slowly (if at all), as opposed to, for example, affiliations, opinions, beliefs or cultural traits. A primary purpose of Blau space is to allow for the representation of relations between individuals. Homophily can be seen in Blau space as the tendency for social ties to be “shorter” rather than “longer” (*i.e.*, more likely to connect individuals who are similar in sociodemographic variables).

Organisations (groups) can be viewed as occupying “niches” in Blau space defined by the locations of their members [18]. These niches may overlap, and competition occurs for members located in the region of intersection. Thus, a system of groups constitutes a space of partially overlapping regions in Blau space, each growing, contracting and moving as members join and leave. The situation becomes even more dynamic when we consider that the sociodemographic composition of a population may change over time, either gradually, as individuals are born, migrate, age, die, and so on, or suddenly, due to events such as war or natural disaster.

2.2 Existing models

A number of models exist that capture aspects of the group formation process in which we are interested.

Opinion dynamics: One important class of models studies the emergence of agreement in groups of people holding diverse opinions on some issue (*e.g.*, [19]). Such models represent individuals as opinion states, and the dynamics as transitions between opinion states. Opinions can be represented as binary, discrete or continuous variables. Various rules for opinion change have been proposed, from simple “voting” or “majority rules” models, where individuals adopt the opinion of one or more of their neighbours, through to more complicated “bounded confidence” models, in which individuals are represented by both an opinion (continuous) and an uncertainty level and influence one another according to the extent that their opinion regions overlap (many of these models are reviewed in [20]).

The conclusions obtained by modelling the dynamics of opinion formation often concern the conditions under which only one opinion prevails, or where two (or more) opinions may co-exist in a population. The basic forms of opinion dynamics models have been elaborated in various ways, such as the addition of noise, the presence of “extremists” who occupy extreme positions in an opinion spectrum, the presence of external perturbations (*e.g.*, due to media influence) and the role played by the topology of the social network (*e.g.*, complete graph, regular lattice, random graph and scale-free network) in determining the stable behaviours of the model. Coevolutionary opinion dynamics models, in which agreement between individuals is used as the basis for social tie creation have also been explored [21].

Cultural evolution: The paradigmatic model of cultural evolution was proposed by Axelrod [22]. He began with the challenge of explaining why, if individuals tended to become more similar over time, we were left with any diversity at all. In Axelrod's model, an individual's culture is defined as a vector of discrete-valued traits. Individuals interact if they share sufficient cultural traits and adopt their neighbours' trait values. Over time, interactions between individuals lead to regions of cultural convergence separated by cultural boundaries (i.e., neighbouring sites who share no cultural traits and hence do not interact). Axelrod found that the number of stable cultures varied with the number of cultural features, and the number of possible traits per feature. There is some overlap between models of opinion formation and cultural evolution, the primary distinction being that opinions are typically modelled as scalar variables, while cultures are modelled as a vector of traits. Axelrod's model has been extended in several different ways, including the addition of noise ("cultural drift"), the effect of network topology, and a coevolutionary version, in which individuals are able to rewire social ties away from culturally dissonant neighbours [23].

Evolution of social structure: A further disparate set of models may be loosely classified as attempts to understand the conditions under which social structure arise. Into this category fall models investigating the role of social norms and the emergence of hierarchical organisation (*e.g.*, as reviewed in [24]). The models presented in [25] use tags as indicators of social identity (that is not necessarily associated with a particular trait) and explore the emergence of cooperative groups in a resource allocation environment.

Each of these models involve some notion of groups, whether they be clusters of opinion, regions of homogeneous culture, or actual organisations. However, affiliation differs from both opinion and culture in several pertinent ways: most opinion dynamics models consider a singly issue (and thus opinion), whereas we wish to allow individuals to have multiple affiliations. The trait vector of the cultural models comes closer to reflecting this situation; however, the inability for an individual to increase or decrease the number of traits they exhibit during a simulation is limiting. Furthermore, the phenomenon of cultural convergence has no meaningful analogy in an affiliation context.

3 Model Description

The model we present here takes its inspiration from aspects of the models reviewed above, and by McPherson and Smith-Lovin's ecological model [8]. Unfortunately, their model is described only in general terms, with considerable

Table 1. Simulation parameter values

Parameter	Value(s)
N	100
M	300
n_+	0.2
n_-	0.1
$n_\emptyset$	0.05
c	0.2
α	0.0, 0.25, 0.5, 0.75, 1.0
β	0.0, 0.25, 0.5, 0.75, 1.0
γ	0.9

omission of mechanisms, equations and parameter values. Our aim was therefore to develop a model with mechanisms that were qualitatively compatible (*i.e.*, informed by the same assumptions), rather than a direct replication.[2]

We model a social network as a simple graph containing N vertices representing individuals, and M undirected edges (initially distributed at random) representing social ties. Each individual i has a location in sociodemographic space i_d, and a set of groups with which they are affiliated i_G. Initially, we consider a single-dimensional space, such that each individual's position is represented by a value on the interval $[0, 1]$. The dynamics of the model are governed by individuals' decisions with regard to their affiliation and neighbourhood. During each iteration, individuals can initiate new groups, recruit neighbours to join groups of which they are a member, leave groups of which they are a member and rewire their social ties.

The likelihood of an individual joining or leaving a group depends upon their local neighbourhood and their current level of commitment. The probability of individual i joining group g is increased by n_+ for each neighbour who is also affiliated with group g, and decreased by n_- for each neighbour who has previously left group g. The probability of joining is also decreased by c for each group with which they are already affiliated. Conversely, the probability of individual i leaving group g is increased by $n_\emptyset$ for each neighbour who is not affiliated with group g, and increased again by n_- for each neighbour who has previously left group g, and decreased by n_+ for each neighbour who is currently affiliated with group g. The probability of leaving is also increased by c for each additional group with which they are affiliated.

In addition, there are three systemic parameters that can be varied: competitiveness, homophily bias and group bias. *Competitiveness* (α) governs the extent to which individuals take their current affiliations into account when joining and leaving groups. If competitiveness is low, an individual's decision to join a new

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[2] The model presented here also builds on our earlier published model [26], but advances it in several respects: group recruitment and social rewiring are now integrated, rather than occurring in discrete phases; more than one group can exist simultaneously, and group membership is no longer necessarily exclusive.

group will not be influenced by the groups with which they are currently affiliated; if competitiveness is high, they are less likely to join new groups when they are already affiliated with others, and more likely to leave groups if they have multiple affiliations. *Homophily bias* (β) governs the extent to which rewiring events are homophilous; when homophily bias is high, individuals will only rewire if doing so will decrease the average social distance between themselves and their neighbourhood. *Group bias* (γ) governs the extent to which rewiring events will increase the proportion of within group ties.

A single iteration of the simulation proceeds as follows[3]:

1. **initiation:** With probability r, select an individual at random and affiliate them with a new group.
2. **recruitment:** Select a random edge from the graph; randomly assign the roles source i and target j to each endpoint. Choose a group g from the set $i_G - j_G$ (*i.e.*, those that source is affiliated with, but target is not). With probability equal to $1 - e^{-x}$ where $x = max[0.01, (|N(i)_{g+}|n_+) - (|N(i)_{g-}|n_-) - (\alpha|i_G|c)]$, j joins group g. We imposed the additional constraint that individuals would *not* rejoin a group of which they had previously been a member and left.
3. **leaving:** Select an individual i, and one of the groups g with which they are affiliated, at random. With probability equal to $1 - e^{-x}$ where $x = max[0.01, (|N(i)_{g-}|n_-) - (|N(i)_{g\emptyset}|n_\emptyset) + (\alpha|i_G|c) - (|N(i)_{g+}|n_+)]$, i leaves group g.
4. **rewiring:** Select a random edge from the graph; randomly assign the roles source i and old target j to each endpoint. With probability γ, choose a potential new target k from the set of co-members of the groups with which i is affiliated, otherwise choose k at random from the population. With probability β, remove the link (i, j) and add the link (i, k) only if the k is closer in sociodemographic space to i than to j.

We set the values of these probability modifiers on the basis of their relative importance as suggested by the literature reviewed above. Values used are listed (along with other simulation parameters) in Table 1.

4 Results

For the purpose of our initial model evaluation (and to enable us to compare our results to those reported in [8]) we ran a series of simulations in which we varied competition (α) and homophily bias (β). Each simulation was run for 50,000 iterations. We quantified the impact of these system level parameters on social structure by measuring observed homophily (Fig. 1)—defined as the mean social distance between neighbours—and the proportion of social ties that connected

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[3] $|N(i)_{g*}|$ is the number of individuals in the neighbourhood of i who are (+) members of group g; (−) ex-members of group g; or ($\emptyset$) not members of group g. $|i_G|$ is the number of groups of which i is currently a member.

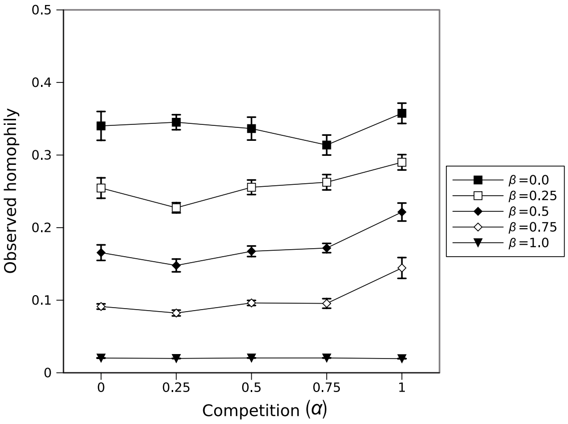

Fig. 1. Observed homophily, for various levels of competition and homophily bias, averaged over the final 10,000 iterations of each simulation run. Error bars show standard deviation. Note that observed homophily is measured as the mean social distance between neighbours, therefore *high* observed homophily equals *low* mean social distance.

neighbours sharing a group (Fig. 2). Each of these were measured over the final 10,000 iterations of a simulation run, to avoid transient effects due to initial conditions. We quantified the effect on group cohesion by measuring group size and longevity, and the location and width of the niche in sociodemographic space occupied by each group. Figs. 3 and 4 show data from two representative runs with different combinations of competition and homophily bias.

Our results indicate that, as observed in [8], homophily bias is directly related to observed homophily, but that high levels of competition decrease the level of observed homophily. As competition increased, individuals belonged to fewer groups, therefore the set of individuals with whom they could form new social ties was smaller, and the social diversity of this set was therefore increased. However, this trend applied only when homophily bias is present at a moderate level. When homophily bias is very high, increased competition has less effect on observed homophily (Fig. 1). An explanation for this is the relative rates of topological community formation and social ordering due to homophilous rewiring events. If isolated communities form prior to social ordering, then observed homophily will be higher than otherwise expected. However, if a population becomes ordered prior to the emergence of isolated communities, then the level of residual diversity in these communities will be low.

Again, in agreement with [8], we observed that, while homophily bias exerted only a marginal influence on the proportion of ties within a group, competition exerted a considerably stronger bias (Fig. 2). When competition was high, individuals were forced to leave groups more frequently; however, they (temporarily at least) retain their ties to continuing members of that group, decreasing its proportion of internal ties.

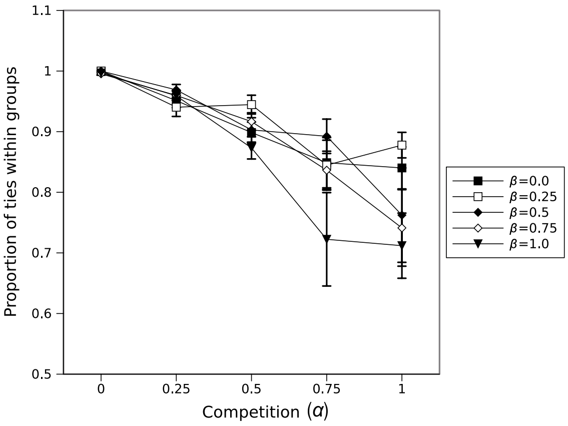

Fig. 2. The proportion of ties that are within groups, for various levels of competition and homophily bias, averaged over the final 10,000 iterations of each simulation run. Error bars show standard deviation.

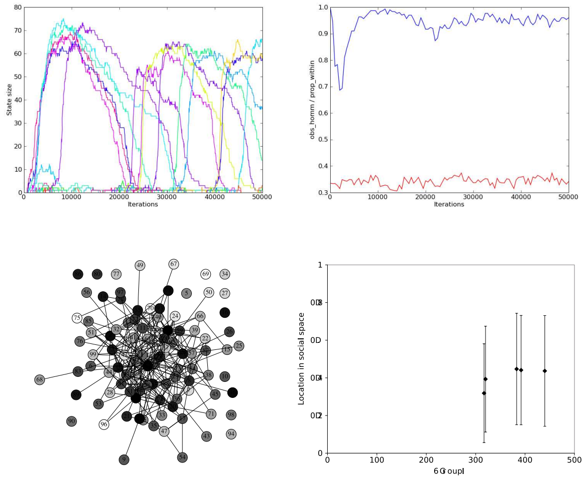

Fig. 3. An example simulation run with low homophily bias ($\alpha = 0.00$) and low competition ($\beta = 0.25$), showing: **A.** evolution of group sizes, **B.** evolution of observed homophily (ref) and proportion of in-group ties (blue), **C.** final network structure, with nodes coloured by social location (black = 0.0; white = 1.0); and **D.** group niches at the the end of the run. From these illustrations we can observe that, at their height, groups tend to be large (60-70 individuals), observed homophily does not deviate significantly from that of a random network, network structure remains densely connected, and group niches are broad and overlapping.

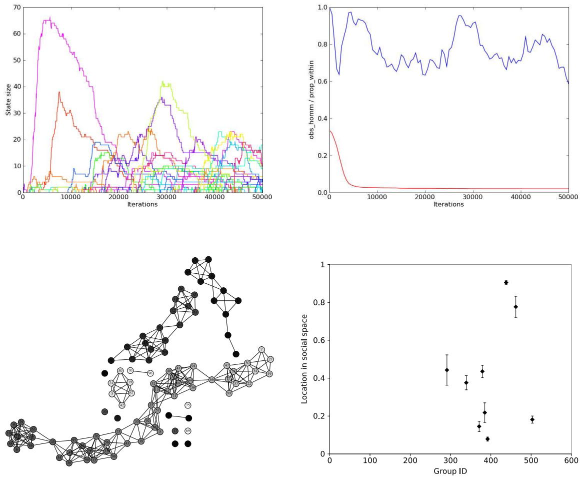

Fig. 4. An example simulation run with high homophily bias ($\alpha = 0.75$) and low competition ($\beta = 1.00$). See Fig. 3 for panel descriptions. In contrast to Fig. 3, we observe that groups tend to be smaller (10-30 individuals, apart from one early group that is able to attract most individuals in a population), observed homophily is high (low distance between neighbours), network structure decomposes into a collection of disconnected and relatively homogeneous communities, and group niches are much narrower and less frequently overlap.

In terms of group characteristics, increasing either competition or homophily bias resulted in a decrease to group size (panel A in Figs. 3 and 4). Increasing competition decreased the number of groups observed to coexist in a population, whereas increasing homophily bias increased the number of groups. The effect of the system parameters on group duration was more ambiguous, with no clearly observable trend. In line with expectations, increasing the level of competition resulted in groups occupying narrower niches, with less overlap between niches (panel D in Figs. 3 and 4).

5 Discussion

To summarise, we have presented a coevolutionary model of social network evolution and group affiliation dynamics. The assumptions made during the development of our model have been based primarily on literature surrounding the ecological theory of group affiliation developed by McPherson and colleagues. To the extent of our current analysis, our model, despite differing in design from that used in [8], captures qualitatively similar relationships between variables and behaviours.

The simulations reported here constitute a first evaluation of our group affiliation model. As with the development of any such model, assumptions and simplifications are made that may influence the core behaviour of the model, and understanding the implications of these is a necessary task. One aspect of the model that requires further attention is the nature of the starting condition and initial transient behaviour. Panel A of Fig. 4 reveals an early group spreading across throughout almost three quarters of the population in the absence of significant competition from other established groups. The presence of this large group facilitates a rapid increase in observed homophily (Panel B of Fig. 4). We have experimented with other initial conditions (such as randomly assigning individuals to groups) but the emergence of an initial dominant group seems to persist. A second aspect warranting further attention is the absence of time dependence in the affiliation decisions. Currently, an individual is as likely to leave a group of which they have been a member for many thousands of iterations as they are to leave one that they joined far more recently, whereas intuition suggests that individuals may be less likely to leave organisations invested significant time and effort in the past.

One criticism of McPherson's ecology of affiliation approach to understanding organisational dynamics is that it leaves no role for agency [15, 9]. In essence, societal and organisational change will proceed according to the dictates of environmental change and coevolution with other organisations irrespective of any action on the part of the individuals or organisations concerned. This conclusion seems unsatisfying, as organisations are capable of adopting different strategies in response to a resource environment. For example, one study of how a group's choice of recruitment strategy can influence its efficacy is that by Weinstein [27], who considers the influence that the availability of material resources to finance recruitment has on the character of recruits attracted to rebel groups in four African nations. One long-term goal of the model we propose is to explore the potential of organisations to structure the way in which they seek to attract and retain individuals in such a way as to work with the impersonal dynamics of competition and selection, rather than merely following its dictates.

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