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Conformity biased transmission in social networks

Andrew Whalen*, Kevin Laland

School of Biology, University of St Andrews, Harold Mitchel Building, St Andrews, Fife, KY16 9TH, UK

HIGHLIGHTS

- We modeled the invasion of novel behaviors through social networks.
- Network structure, conformity bias, and learning biases were varied.
- When learners used a conformity bias novel behaviors were less likely to spread.
- Gross network structure had limited impact on the likelihood a novel behavior spread.
- However, high degree nodes were disproportionately the source of novel behaviors.

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ABSTRACT

In this paper we explore how the structure of a population can differentially influence the spread of novel behaviors, depending on the learning strategy of each individual. We use a series of simulations to analyze how frequency dependent learning rules might affect how easily novel behaviors can spread through a population on four artificial social networks, and three real social networks. We measured the likelihood that a novel behavior could spread through the population, and the likelihood that there were multiple behavioral variants in the population, a measure of cultural diversity. Surprisingly, we find few differences between networks on either measure. However, we do find that where a behavior originated on a network can have a substantial impact on the likelihood that it spreads, and that this location effect depends on the learning strategy of an individual. These results suggest that for first-order analysis of how behaviors spread through a population, social network structure can be ignored, but that the social network structure may be useful for more fine-tuned analyses and predictions.

1. Introduction

Many animals are able to learn behaviors socially, by attending to the behavior of other individuals (Laland and Galef, 2009). This allows individuals to learn novel behaviors more quickly and cheaply than through asocial trial-and-error. One important consequence of social learning lies in its ability to facilitate the transmission of behavioral variants through a population. However social learning is not intrinsically adaptive (Rogers, 1988; Rendell et al., 2010). Theoretical models suggest that in order for social learning to increase the fitness of animals in a population, individuals must be selective in *who*, *when*, and *how* they use social information (Boyd and Richerson, 1985; Rogers, 1988; Henrich and McElreath, 2003; Laland, 2004; Rendell et al., 2011). This implies that animals will rarely copy others randomly, a theoretical finding that is borne out by extensive research into animals and human social learning (Hoppitt and Laland, 2013). Heuristics specifying the circumstances under which individuals copy others are often termed 'social learning strategies' (Laland, 2004), although 'transmission' biases (Boyd and Richerson, 1985; Henrich and McElreath, 2003) and 'trust' (Corriveau and Harris, 2010) are related concepts. Previous research has employed theoretical and computational tools to examine these questions (see Rendell et al., 2010; Hoppitt and Laland, 2013). However much of this research has treated *who* and *how* questions independently. In this paper we examine together how the choice of *whom* an individual learns from, and *how* they learn, collectively affect how novel behaviors spread through a social network.

We build on a long line of modeling research looking into the *how* question by analyzing what types of strategies are likely to evolve in unstructured populations. In early work on this topic, Boyd and Richerson (1985) explored the evolutionary outcomes of a conformity biased transmission strategy in a spatially variable environment, and concluded that human social learning should commonly evolve to exhibit a conformity bias. They defined conformity biased transmission (henceforth 'conformist transmission') as transmission where the likelihood of adopting the majority behavior was greater than the observed frequency of

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* Corresponding author. Tel.: +44 01334 463009.
E-mail address: aczw@st-andrews.ac.uk (A. Whalen).

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the behavior in the population. Subsequently, Henrich and Boyd (1998) found that in a spatially and temporally changing environment, conformist transmission would evolve whenever social learning would evolve. Wakano and Aoki (2007) extended and upheld these results, but concluded that a very strong conformity bias might not be adaptive, because it may present novel beneficial behaviors from spreading through the population, thus limiting the advantage of social learning. Both Nakahashi et al. (2012) and Kandler and Laland (2013) reached similar conclusions; the first using an island model, where individuals were spread on a series of environmentally varying islands, and the second using reaction-diffusion models. These results suggest that conformity biased transmission is likely to be adaptive under a wide variety of situations.

While the above studies do explore both *who* individuals learn from (e.g. learning from island neighbors) and *how* they do (applying a conformist transmission rule), their representation of social structure is at best, relatively crude. Many of these models examine social structures at a comparatively large scale that driven by differences in the underlying environmental structure. In reality social structure will arise at several different scales, including within demes. Directed social learning may arise through more fine-grained spatial structure, where individuals disproportionately learn from others that are physically proximate, or more salient in some other respect, compared to individuals within the same deme but more distant in space, or less attractive as models. Social structure may play an important role in the value of social learning since the value of social information depends not only on how you use it, but also from whom it came. If the structure of the population inhibits the spread of novel behaviors, it may decrease the usefulness of social learning. Conversely, if the structure allows only beneficial behaviors to spread, it may increase the usefulness of social learning. Thus, it is likely that the usefulness of a given learning strategy, like conformity biased copying, may depend on the relationships of who learns from whom. We call this set of relationships the social network of the population.

We set out to explore how the structure of the social network will influence the spread of behaviors through a population, and how this will be affected by the learning strategies deployed.

2. Evolutionary dynamics in structured populations

How the network structure of a population influences the spread of traits through a population is not a problem unique to social learning; a similar question arises with respect to the spread of novel alleles through structured populations. Evolutionary theorists have addressed this issue by examining how the social network of a population (often described as a "graph") can mediate the interplay between selection and drift. Lieberman et al. (2005) used a simple evolutionary model, the Moran model, to examine the selective properties of certain graphs. In the Moran model, individuals are placed at the nodes of a graph, and reproduce with probability proportional to their fitness. Their child replaces the individual at a neighboring node, to which they are connected on the social network. Lieberman et al. found that under this process, the structure of many "normal" graphs did not influence selection. The normality condition required is that the graph has to be *isothermal*: each node is equally likely to replace a neighbor as it is to be replaced by a neighbor. Isothermal graphs include degree-regular graphs, a type of graph where every node has the same number of neighbors. Recent work has extended this result, large random graphs as well, whose dynamics with asymptotically approach those of freely mixing populations as the graph grows large (Adlam and Nowak, 2014).

However on smaller non-isothermal graphs, Lieberman et al. found that selection was enhanced on variants of a "star" graph, a type of network that has many weakly connected components connected through a small handful of nodes.

Selection was reduced, and drift enhanced on some directed graphs, particularly those that had an asymmetric relationship between two subsets of nodes (where one subset could replace the other, but not in turn be replaced). Although the graphs considered may not represent real populations, these findings nevertheless suggest that the structure of a population may influence the selection on genetic traits. However, these conclusions will not necessarily map onto cultural processes, because of differences between genetic and cultural dynamics.

In cultural processes the pathways of information transmission may be different from those of biological systems. In biological systems information is typically transmitted vertically from parent to child, although lateral gene transfer is increasingly recognized as important, particularly in prokaryotes (Koonin et al., 2001). Also, and again with some exceptions, in eukaryote evolution offspring rarely have more than two genetic parents. In contrast, a social learner may learn from multiple individuals – not just parents but teachers, elders, siblings, friends, and peers and may seek out suitable cultural parents from whom to learn.

Hence cultural information passes not just vertically, but also horizontally and obliquely, frequently with multiple tutors involved (Cavalli-Sforza and Feldman, 1981). The Moran model captures the biological intuition in how it defines sexual reproduction. At each reproductive event a parent is selected and chosen to reproduce, with the offspring replacing a neighbor. For a cultural process, the reverse might be more natural; an 'offspring' is selected to learn, and then learns from one (or many) of their neighbors. This 'reproductive' model is known as the voter model (Castellano, 2012), and has been explored in the context of opinion dynamics.

The voter model, like the Moran model, is based on a birth–death process on a graph. At each update, a new learner is selected from the population at random. That learner selects a teacher to learn from and adopts the behavior (or belief) of their teacher. Given their similarities, it is unsurprising that the dynamics of the voter model are similar to those of the Moran model. Antal et al. (2006) explored both models and found that, just as in the Moran model, with the voter model the likelihood that a novel behavior becomes fixed in a population is the same for all degree-regular graphs (graphs where all individuals have the same number of neighbors). However for degree heterogeneous graphs they found that the probability of fixation was proportional to the degree of the initial (mutant) node in the voter model, and inversely proportional to the degree of the initial node for the Moran model.

Much of the past work on the voter model has assumed that learners use random copying to adopt a novel behavior. However extensive theoretical work suggests that human adults and children, and other animals strategically copy other individuals. What is required is a detailed analysis of how strategic copying influences information spread through social networks.

One learning strategy of particular significance is conformity biased learning, which has strong theoretical and empirical support in humans (Morgan et al., 2012; McElreath et al., 2005; Efferson et al., 2008; Morgan et al., 2012), children (e.g. Harris and Corriveau, 2011; Fusaro and Harris, 2008; Corriveau et al., 2009) and animals (Pike and Laland, 2010). Conformity bias is a non-random and non-linear learning rule, where the probability of adopting a behavior depends non-linearly on the frequency of that behavior in the population (Boyd and Richerson, 1985). The dynamics of the voter model when individuals deploy a non-linear learning rule are not well understood, since the population-level dynamics become analytically intractable in nearly all situations.