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# The mass media destabilizes the cultural homogenous regime in Axelrod's model

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**Abstract**

An important feature of Axelrod's model for culture dissemination or social influence is the emergence of many multicultural absorbing states, despite the fact that the local rules that specify the agents interactions are explicitly designed to decrease the cultural differences between agents. Here we re-examine the problem of introducing an external, global interaction—the mass media—in the rules of Axelrod's model: in addition to their nearest neighbors, each agent has a certain probability $p$ to interact with a virtual neighbor whose cultural features are fixed from the outset. Most surprisingly, this apparently homogenizing effect actually increases the cultural diversity of the population. We show that, contrary to previous claims in the literature, even a vanishingly small value of $p$ is sufficient to destabilize the homogeneous regime for very large lattice sizes.

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## 1. Introduction

Why do people have different opinions given that after repeated interactions some consensus should emerge? Why are there different cultures given that modern media has apparently succeeded in transforming the planet into a global village [1]? These are the issues addressed by Axelrod's model for the dissemination of culture or social influence [2], which is considered the paradigm for idealized models of collective behavior which seek to reduce a collective phenomenon to its functional essence [3].

Building on just a few simple principles, Axelrod's model provides highly nontrivial answers to those questions. In Axelrod's model, an agent—an individual or a culturally homogeneous village—is represented by a string of $F$ cultural features, where each feature can adopt a certain number $q$ of distinct traits. The interaction between any two agents takes place with probability proportional to their cultural similarity, i.e. proportional to the number of traits they have in common. The result of such interaction is the increase of the similarity between the two agents, as one of them modifies a previously distinct trait to match that of its partner. We note that there are many alternative models of social influence or opinion formation [4–6] which, similarly to Axelrod's, focus on the interplay between consensus and diversity, and which have also been extensively studied by the statistical physics community (see [7] for a recent review).

Notwithstanding the built-in assumption that social actors have a tendency to become more similar to each other through local interactions [8, 9], Axelrod's model does exhibit global polarization, i.e. a stable multicultural regime [2]. More important, however, at least from the statistical physics perspective, is the fact that the competition between the disorder of the initial configuration and the ordering bias of the local interactions produces a nontrivial threshold phenomenon (more precisely, a nonequilibrium phase transition) which separates in the space of parameters of the model the globally homogeneous from the globally polarized regimes [10, 11].

A feature that sets Axelrod's model apart from most lattice models which exhibit nonequilibrium phase transitions [12] is the fact that all stationary states of the dynamics are absorbing states, i.e. the dynamics freezes in the long-time regime [10]. This is so because, according to the rules of Axelrod's model, two neighboring agents who do not have any cultural trait in common cannot interact and the interaction between agents who share all the cultural traits does not change their cultural features. Hence, at equilibrium we can safely predict that, regarding their cultural features, any neighbor of a given agent is either identical to or completely different from it. This is a double-edged sword: on the one hand, we can easily identify the stationary regime, which is a major problem in the characterization of nonequilibrium phase transitions [13, 14]; on the other hand, the dynamics can take an arbitrarily large time to freeze for some parameter settings and initial conditions [10, 11, 15, 16].

The key ingredient for the existence of a stable globally polarized state is the rule that prohibits the interaction between completely different agents (i.e. agents which do not have a single cultural trait in common). This was first pointed out by Kennedy [17] who relaxed this rule and permitted interactions regardless of the similarity between agents. As a result, the system evolved until all agents became identical, i.e. the only absorbing states were the homogenous ones. (There are $q^F$ distinct absorbing homogenous configurations.) In addition, Klemm *et al* [18] have shown that the introduction of external noise to the dynamics so that a single trait of an arbitrarily chosen agent was changed at random ends up destabilizing the polarized state. Moreover, expansion of communication modeled by increasing the connectivity of the lattice [19, 20] or by placing the agents in more complex networks [21] (e.g. small-world and scale-free networks) also resulted in cultural homogenization.

It should be mentioned, however, that other models of social influence seem to yield a more robust polarized state. For instance, the frequency bias mechanism [22, 23] for cultural or opinion change assumes that the number of people holding an opinion is the key factor for an agent to adopt that opinion, i.e. people have a tendency to espouse cultural traits that are more common in their social environment. Parisi *et al* [24] have replaced the rules of Axelrod's model by the frequency bias mechanism (essentially, a majority rule) and found a stable polarized state for small lattices. Since similarity plays no role in the agents' interactions, the frequency bias mechanism is naturally robust to noise.

The impression is then that the globally polarized (multicultural) state is very frail, being disrupted by any (realistic or not) extension of the original model. In view of this, it came as a big surprise when Shibanai *et al* [25] found that the introduction of a homogeneous media effect (i.e. it is the same for all agents) aiming at influencing the agents' opinions actually favors polarization. This finding is at odds with the common-sense view that mass media, such as newspapers and television, are devices that can be effectively used to control people's opinions and so homogenize society. Of course, the effect of media in real personal networks is complicated and seems to follow the so-called 'two-step flow of communication' in which the media affect opinion leaders first, who then influence the rest of the population [26]. In fact, personal networks seem to serve as a buffer for the media effect.

Although this counterintuitive effect of the mass media has been extensively investigated (see, e.g., [27–31]), there is still no first-principles explanation for it. The research has focused mostly on the search for a threshold on the intensity of the media influence such that above that threshold, the population would become polarized and below it, the population would becomes culturally homogeneous. In this contribution we show that such threshold is in fact an artifact of finite lattices: when a careful analysis of the finite-size effects is carried out, we find that even a vanishingly small media influence is sufficient to destabilize the culturally homogeneous regime.

The rest of this paper is organized as follows. In section 2 we describe the original Axelrod's model, discuss at some length the basic assumptions of the model and introduce the effect of an external fixed media [27, 28]. In section 3 we present an efficient algorithm to simulate Axelrod's model. The simulation results as well as a discussion of our main results are presented in that section. Finally, in section 4 we present our concluding remarks.

## 2. Model

In Axelrod's model each agent is characterized by a set of $F$ cultural features which can take on $q$ distinct values. Hence, an agent is represented by a string of symbols, e.g. 13 255 in the case of $F = 5$ and $q = 5$. Clearly, for this parameter setting there are only $q^F = 3125$ different cultures. The agents are fixed in the sites of a square lattice of size $L \times L$ with periodic boundary conditions and can interact only with their four nearest neighbors. The initial configuration is completely random with the features of each agent given by random integers drawn uniformly from 1 to $q$. Each time an agent at random (this is the target agent) is chosen as well as one of its neighbors. These two agents interact with probability equal to their cultural similarity, defined as the fraction of common cultural features. For instance, assuming that the target agent is described by the string 13 255 and its neighbor by 13 425, the interaction occurs with probability 3/5. In case the interaction action is not selected, we choose another target agent at random and repeat the procedure. An interaction consists of selecting at random one of the distinct features, and changing the target agent's trait on this feature to the neighbor's corresponding trait. Returning to our example, if the third feature is chosen the target agent becomes 13 455 and its neighbor remains unchanged. This procedure is repeated until the system is frozen in an absorbing configuration.

The basic assumption of Axelrod's model is that similarity is a main requisite for social interaction and, as a result, exchange of opinions. This is the 'birds of a feather flock together' hypothesis which states that individuals who are similar to each other are more likely to interact and then become even more similar [9]. (A similar assumption has been used to model the interspecies interactions in spin-glass like model ecosystem [32].) Recent empirical evidence in favor of this assumption comes from the analysis of Web 2.0 social networks [33]. A study of a population of over $10^7$ people indicates that people who chat with each other using instant messaging are more likely to have common interests, as measured by the similarity of their Web searches, and the more time they spend talking, the stronger this relationship is. We note, however, that this assumption is disputed by other researchers who argue that people are attracted to others who resemble their ideal, rather than their actual selves [34].

To introduce the effect of a global media following the seminal paper by Shibanai *et al* [25], we need first to define a virtual agent whose cultural traits reflect the media message. In [25], each cultural feature of the virtual agent has the trait which is the most numerous in the population—the consensus opinion. Here we choose to keep the media message fixed from the outset, so it really models some alien influence impinging on the population. Explicitly, we generate the culture vector of the virtual agent at random and keep it fixed during the dynamics. Next, we need to specify how the media interact with the real agents. To do that we introduce a new control parameter $p \in [0, 1]$, which measures the strength of the media influence. As in the original Axelrod's model, we begin by choosing a target agent at random, but now it can interact with the media with probability $p$ or with its neighbors with probability $1 - p$. Since we have defined the media as a virtual agent, the interaction follows exactly the same rules as before. The original model is recovered for $p = 0$, provided we properly define the halting criterion of the dynamics, as discussed in the next section.

## 3. Results

To simulate efficiently Axelrod's model we make a list of the active agents. An active agent has at least one feature in common and at least one distinct feature with at least one of its four nearest neighbors. Clearly, since only active agents can change their cultural features, it is more efficient to select the target agent randomly from the list of active agents rather than from the entire lattice. Note that the randomly selected neighbor of the target agent may not necessarily be an active agent itself. In the case that the cultural features of the target agent are modified by the interaction with its neighbor, we need to re-examine the active/inactive status of the target agent, as well as of all its neighbors, so as to update the list of active agents. The dynamics is frozen when the list of active agents is empty. This is the halting criterion we mentioned in the last section.

The important point in this halting criterion is that the virtual agent does not enter the procedure to determine whether a real agent is active or not; otherwise the dynamics would not freeze. Actually, there are only two situations where the dynamics could freeze in the case the virtual agent is used in that procedure: in the uniform regime where all agents become identical to the virtual agent, and in a two-domains regime where one domain is identical to the virtual agent and the other is completely opposed (there are $(q - 1)^F$ distinct realizations of this possibility). However, since the dynamics does not in general lead to these situations, it becomes stuck in a trite position in which changes occur due to the interaction with the virtual agent only. Although it has never been explicitly pointed out, this must have been the halting criterion used in previous analyses of the effect of media in Axelrod's model [25, 27–30].

In order to explore fully the dependence of the frozen configuration on the lattice size, in this contribution we restrict our analysis to the parameter setting $F = q = 5$, which guarantees that the model without external field (media) is in the homogeneous phase of its phase diagram [28]. A feature that sets our results apart from those reported previously in the literature is that our data points represent averages over at least $10^3$ independent runs for lattices of linear size up to $L = 3000$. (For comparison, we note that the results of [27, 28] are derived from simulations of lattices with $L = 40$ and 50 independent runs.) This requires a substantial computational effort, especially in the regime where the number of cultures decreases with the lattice size since then the time for absorption can be as large as $10^6 \times L^2$. In the figures presented in the following, the error bars are smaller or at most equal to the symbol sizes.

For our purposes, the frozen configuration can be characterized by the ratio between the number of clusters (or cultural domains) $S$ and the lattice area $L^2$. A cluster is simply a bounded region of uniform culture. In the case of diasporas [19], the two or more cultural

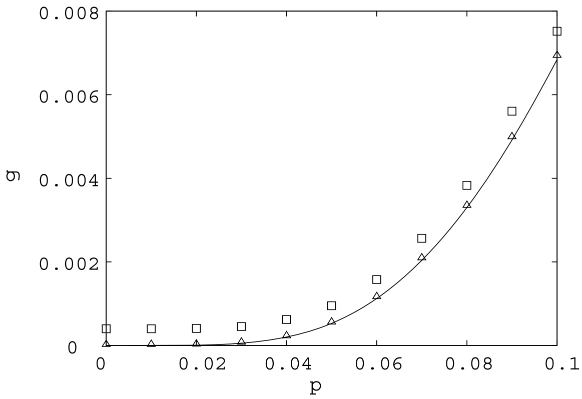


**Figure 1.** Ratio $g$ between the number of cultural domains and the lattice area as a function of the strength of the media influence for $L = 50$ (□) and 200 (△). The solid line is the result of the extrapolation of the data to the limit $L^2 \to \infty$. The parameters are $F = 5$ and $q = 5$.

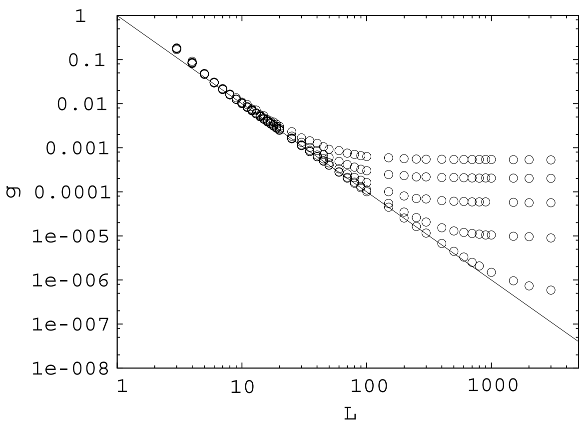


**Figure 2.** Logarithmic plot of the ratio $g$ as function of the linear size $L$ of the lattice for (top to bottom) $p = 0.05, 0.04, 0.03, 0.02$ and 0.01. The solid straight line is $1/L^2$, which corresponds to the value of $g$ in the uniform regime. The parameters are $F = 5$ and $q = 5$.

domains (which are characterized by the same culture) are counted separately. We note that since $S$ is bounded by $L^2$ we have $g \equiv S/L^2 \leqslant 1$. In the uniform regime we have $S = 1$ and so $g = 1/L^2$. Figure 1 exhibits this measure as a function of the strength of the media influence $p$ for different lattice sizes. The suitability of the measure $g$ is demonstrated by the fact that the data converge to well-defined values (solid line in figure 1) as the lattice size is increased. In other words, $S$ increases with $L^2$ for $p$ not too small. Indeed, from figure 1 it seems that the measure $g$ vanishes for small $p$ which would indicate the existence of a minimum strength value $p_c$, above which the uniform regime is destabilized [27–30]. Visual inspection of the data shown in figure 1 yields $p_c \approx 0.03$, which agrees with the estimate of [28] (see their figure 3).

A more careful analysis reveals a different story, however, as shown in figure 2. In fact, consider the data for $p = 0.01$, which is well below our initial estimate, $p_c \approx 0.03$. An analysis of lattices of sizes up to $L = 600$ indicates a clear tendency of convergence towards

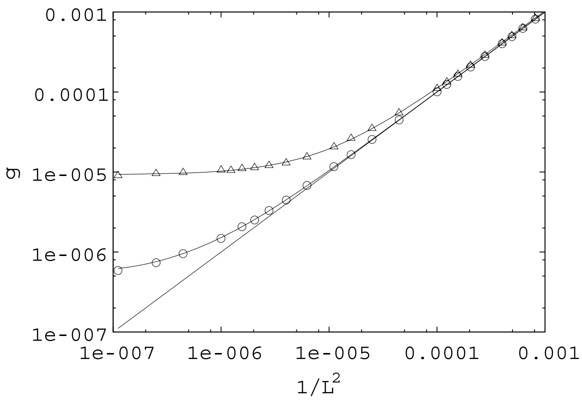


**Figure 3.** Ratio $g$ between the number of cultural domains and the lattice area as function of the reciprocal of the lattice area $1/L^2$ for $p = 0.02$ (△) and 0.01 (○). The solid lines are the fittings $g = B_p + A_p/L^2$ and the dashed straight line is the function $1/L^2$. The parameters are $F = 5$ and $q = 5$.

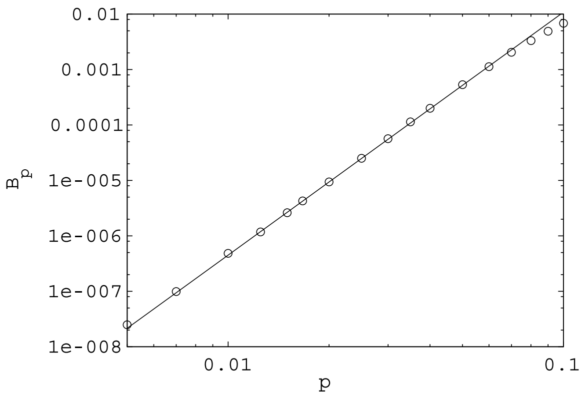


**Figure 4.** The ratio between the number of cultural domains and the lattice area for $L \to \infty$ obtained through the extrapolation procedure shown in figure 3 as a function of the strength $p$ of the media influence. The straight line is the fitting given by equation (1). The parameters are $F = 5$ and $q = 5$.

the uniform regime (i.e. $g = 1/L^2$ fits the data almost perfectly in that range of $L$), but this trend changes completely when lattices of sizes greater than $L = 1000$ are considered. In this case, rather than vanishing as $1/L^2$, $g$ tends to a nonzero value when $L \to \infty$. To verify whether this finding holds true for all values of $p$ we need first estimate the value of $g = g(p)$ for infinite lattices and nonzero $p$ and then try to figure out the dependence of the extrapolated value of $g$ on $p$ in the limit $p \to 0$. As suggested by figure 2, direct simulations using small values of the parameter $p$ would require very large lattice sizes in order to produce significative deviations from the uniform regime.

Figure 3 illustrates the procedure used to obtain the measure $g$ in the limit $L \to \infty$. The key point is the use of the fitting function $g(p) = B_p + A_p/L^2$ which describes the data very well for $L > 500$: the statistical error in the estimate of $B_p = \lim_{L\to\infty} g(p)$ is less than 2% for all values of $p$ considered here. The solid curve shown in figure 1 was obtained by following this procedure. Finally, figure 4 presents the dependence of $B_p$ on $p$. For small $p$

the data are fitted very well by the equation

$$B_p = \lim_{L\to\infty} g(p) = (260 \pm 29)\, p^{4.38\pm0.03}, \tag{1}$$

as indicated in the figure. The large value of the power of $p$ may explain why the numerical simulations yielded a nonzero value for $p_c$: for small $p$ it is virtually impossible to distinguish the result of equation (1) from zero.

In sum, Axelrod's model does not exhibit a phase transition for $p > 0$: the only stable regime for infinite lattice sizes is the polarized one. Strictly, this conclusion is valid for a single setting of the control parameters, namely, $F = q = 5$, but we see no reason why it should not hold for other values of these parameters as well.

## 4. Conclusion

In this contribution we have revisited an important extension of Axelrod's model in which, in addition to the local interactions between agents, there is a global element—the media—that influences the agents' opinions or cultural traits [25]. In stark contrast to the common-sense opinion that the media effect is to homogenize the society, we find, in agreement with previous studies [25, 27–30], that the media actually promotes polarization or the diversity of opinions. However, we have shown that this effect is so powerful that a vanishingly small influence strength $p$ is sufficient to destabilize the cultural homogenous state for very large lattices. This finding calls for a re-examination of the claim, which is based on the analysis of small lattices, that there exists a threshold value $p_c$ below which the homogeneous state is stable.

Although our results were obtained for a fixed external field (media), they are expected to also hold for a site-independent global autonomous field, as in the original media model [25], as well as for a site-dependent local field [28]. In fact, if the homogeneous state is destabilized by a uniform field, then chances are that it will also be destabilized by external fields that vary in time (global media) or in time and space (local media).

A word is in order about a most curious finding presented in [28]: if the parameters $q$ and $F$ are set such that the frozen configurations are polarized at zero field (i.e. for $p = 0$), then the introduction of an external field seems to favor the homogeneous state in the limit $p \to 0$. Our main objection to that finding is that the parameter setting $F = 5$ and $q = 30$ used in that analysis (see figure 7 of [28]) actually corresponds to the homogeneous regime, rather than to the polarized one, of the zero-field model (data not shown). The large value of $q$ enhances the finite size effects and makes the convergence to the uniform regime prohibitively slow for $L > 400$, so it would be inadvisable to draw any bold conclusions in such adverse scenario.

At present we have no idea why the media promotes polarization rather than the expected homogenization. An analysis of the distribution of sizes of the cultural domains as well as of the distance between domains may provide some clue to this counterintuitive effect. Work in this line is under way.

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