

EFFECTS OF MASS MEDIA AND CULTURAL DRIFT IN A MODEL FOR SOCIAL INFLUENCE

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In the context of an extension of Axelrod's model for social influence, we study the interplay and competition between the cultural drift, represented as random perturbations, and mass media, introduced by means of an external homogeneous field. Unlike previous studies [J. C. González-Avella *et al.*, *Phys. Rev. E* **72**, 065102(R) (2005)], the mass media coupling proposed here is capable of affecting the cultural traits of any individual in the society, including those who do not share any features with the external message. A noise-driven transition is found: for large noise rates, both the ordered (culturally polarized) phase and the disordered (culturally fragmented) phase are observed, while, for lower noise rates, the ordered phase prevails. In the former case, the external field is found to induce cultural ordering, a behavior opposite to that reported in previous studies using a different prescription for the mass media interaction. We compare the predictions of this model to statistical data measuring the impact of a mass media vasectomy promotion campaign in Brazil.

Keywords: Sociophysics; econophysics; marketing; advertising.

The non-traditional application of statistical physics to many problems of interdisciplinary nature has been growing steadily in recent years. Indeed, it has been recognized that the study of statistical and complex systems can provide valuable tools and insight into many emerging interdisciplinary fields of science.^{1–3} In this context, the mathematical modeling of social phenomena allowed to perform quantitative investigations on processes such as self-organization, opinion formation and spreading, cooperation, formation and evolution of social structures, etc. (see e.g., Refs. 4–9). In particular, a model for social influence proposed by Axelrod,^{10,11} which aims

at understanding the formation of cultural domains, has recently received much attention¹²⁻¹⁸ due to its remarkably rich dynamical behavior.

In Axelrod's model, culture is defined by the set of cultural attributes (such as language, art, technical standards, and social norms¹¹) subject to social influence. The cultural state of an individual is given by their set of specific traits, which are capable of changing due to interactions with their acquaintances. In the original proposal, the individuals are located at the nodes of a regular lattice, and the interactions are assumed to take place between lattice neighbors. Social influence is defined by a simple local dynamics, which is assumed to satisfy the following two properties:

- (a) social interaction is more likely to take place between individuals that share some or many of their cultural attributes;
- (b) the result of the interaction is that of increasing the cultural similarity between the individuals involved.

By means of extensive numerical simulations, it was shown that the system undergoes a phase transition separating an ordered (culturally polarized) phase from a disordered (culturally fragmented) one, which was found to depend on the number of different cultural traits available.¹² The critical behavior of the model was also studied in different complex network topologies, such as small-world and scale-free networks.¹⁵ These investigations considered, however, zero-temperature dynamics that neglected the effect of fluctuations.

Following Axelrod's original idea of incorporating random perturbations to describe the effect of *cultural drift*,¹⁰ noise was later added to the dynamics of the system.¹⁴ With the inclusion of this new ingredient, the disordered multicultural configurations were found to be metastable states that could be driven to ordered stable configurations. The decay of disordered metastable states depends on the competition between the noise rate, r , and the characteristic time for the relaxation of perturbations, T . Indeed, for $r \leq T^{-1}$, the perturbations drive the disordered system towards monocultural states, while for $r \geq T^{-1}$, the noise rates are large enough to hinder the relaxation processes, thus keeping the disorder. Since T scales with the system size, N , as $T \sim N \ln N$, the culturally fragmented states persist in the thermodynamic limit, irrespective of the noise rate.¹⁴

More recently, an extension of the model was proposed, in which the role of *mass media* and other mass external agents was introduced by considering external¹⁶ and autonomous local or global fields,¹⁷ but neglecting random fluctuations. The interaction between the fields and the individuals was chosen to resemble the coupling between an individual and their neighbors in the original Axelrod's model. According to the adopted prescription, the interaction probability was assumed to be null for individuals that do not share any cultural feature with the external message. In this way, intriguing, counterintuitive results were obtained: the influence of mass media was found to disorder the system, thus driving ordered, culturally polarized states towards disordered, culturally fragmented configurations.¹⁶

The aim of this work is to include the effect of cultural drift in an alternative mass media scenario. Although still inspired in the original Axelrod's interaction, the mass media coupling proposed here is capable of affecting the cultural traits of any individual in the society, including those who do not share any features with the external message.

For noise rates below a given transition value, which depends on the intensity of the mass media interactions, only the ordered phase is observed. However, for higher levels of noise above the transition perturbation rate, both the ordered (culturally polarized) phase and the disordered (culturally fragmented) phase are found. In the latter case, we obtain an order-disorder phase diagram as a function of the field intensity and the number of traits per cultural attribute. According to this phase diagram, the role of the external field is that of inducing cultural ordering, a behavior opposite to that reported in Ref. 16 using a different prescription for the mass media interaction. In order to show the plausibility of the scenario considered here, we also compare the predictions of this model to statistical data measuring the impact of a mass media vasectomy promotion campaign in Brazil.¹⁹

The model is defined by considering individuals located at the sites of an $L \times L$ square lattice. The cultural state of the i th individual is described by the integer vector $(\sigma_{i1}, \sigma_{i2}, \dots, \sigma_{iF})$, where $1 \leq \sigma_{if} \leq q$. The dimension of the vector, F , defines the number of cultural attributes, while q corresponds to the number of different cultural traits per attribute. Initially, the specific traits for each individual are assigned randomly with a uniform distribution. Similarly, the mass media cultural message is modeled by a constant integer vector $(\mu_1, \mu_2, \dots, \mu_F)$, which can be chosen as $(1, 1, \dots, 1)$ without loss of generality. The intensity of the mass media message relative to the local interactions between neighboring individuals is controlled by the parameter $M (0 \leq M \leq 1)$. Moreover, the parameter $r (0 \leq r \leq 1)$ is introduced to represent the noise rate.¹⁴

The model dynamics is defined by iterating a sequence of rules, as follows:

- (1) an individual is selected at random;
- (2) with probability M , he/she interacts with the mass media field; otherwise, he/she interacts with a randomly chosen nearest neighbor;
- (3) with probability r , a random single-feature perturbation is performed.

The interaction between the i th and j th individuals is governed by their cultural overlap, $C_{ij} = \sum_{f=1}^F \delta_{\sigma_{if}, \sigma_{jf}} / F$, where δ_{kl} is the Kronecker delta. With probability C_{ij} , the result of the interaction is that of increasing their similarity: one chooses at random one of the attributes on which they differ (i.e., such that $\sigma_{if} \neq \sigma_{jf}$) and sets them equal by changing the trait of the individual selected in the first place. Naturally, if $C_{ij} = 1$, the cultural states of both individuals are already identical, and the interaction leaves them unchanged.

The interaction between the i th individual and the mass media field is governed by the overlap term $C_{iM} = (\sum_{f=1}^F \delta_{\sigma_{if}, \mu_f} + 1) / (F + 1)$. Analogously to the precedent case, C_{iM} is the probability that, as a result of the interaction, the individual

changes one of the traits that differ from the message by setting it equal to the message's trait. Again, if $C_{iM} = 1$, the cultural state of the individual is already identical to the mass media message, and the interaction leaves it unchanged. Notice that $C_{iM} > 0$; thus, the mass media coupling used here is capable of affecting the cultural traits of any individual in the society, including those who do not share any features with the external message. As commented above, this differs from the mass media interaction proposed in Ref. 16, which was given by $C'_{iM} = \sum_{f=1}^F \delta_{\sigma_{if}, \mu_f} / F$.

As regards the perturbations introduced in step (3), a single feature of a single individual is randomly chosen, and, with probability r , their corresponding trait is changed to a randomly selected value between 1 and q .

In the absence of fluctuations, the system evolves towards absorbing states, i.e., frozen configurations that are not capable of further changes. For $r > 0$, instead, the system evolves continuously, and, after a transient period, it attains a stationary state. In order to characterize the degree of order of these stationary states, we measure the (statistically-averaged) size of the largest homogeneous domain, S_{\max} .^{12,14} The results obtained here correspond to systems of linear size $L = 50$ and a fixed number of cultural attributes, $F = 10$, typically averaged over 500 different (randomly generated) initial configurations.

Figure 1 shows the order parameter, S_{\max}/L^2 , as a function of the noise rate, r , for different values of the mass media intensity. The number of different cultural traits per attribute is $q = 40$. As anticipated, for small noise rates, the perturbations drive the decay of disordered metastable states, and thus the system presents only ordered states with $S_{\max}/L^2 \approx 1$. As the noise rate is gradually increased, the competition between characteristic times for perturbation and relaxation processes

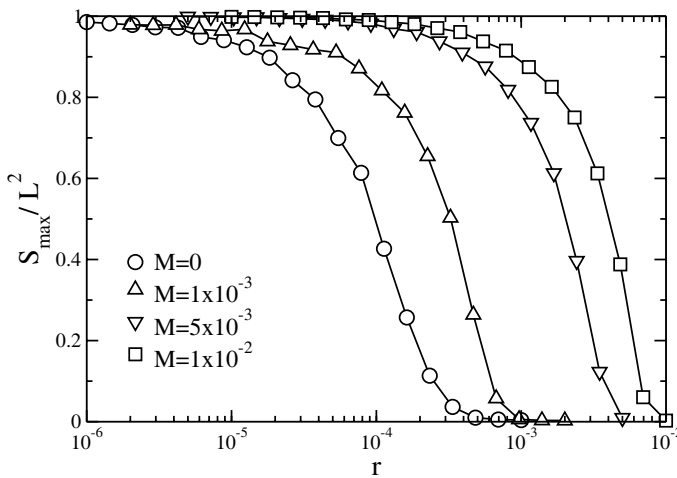


Fig. 1. Order parameter, S_{\max}/L^2 , as a function of the noise rate, r , for different values of the mass media intensity M , as indicated. The number of different cultural traits per attribute is $q = 40$. The lines are guides to the eye.

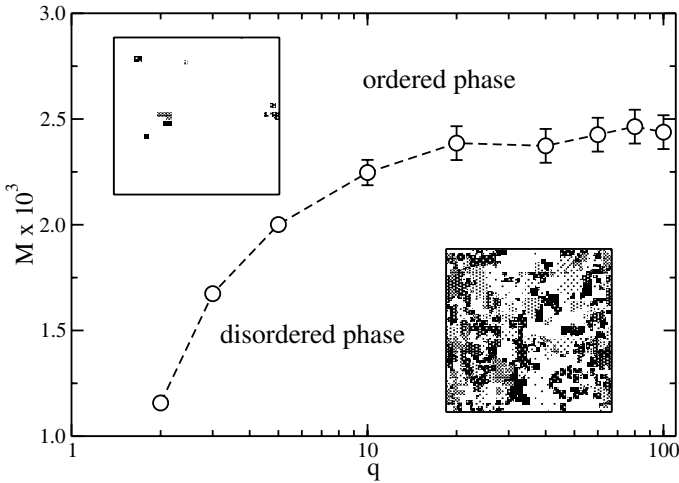


Fig. 2. Phase diagram showing the separation between the ordered (culturally polarized) phase and the disordered (culturally fragmented) phase, for the noise rate $r = 10^{-3}$. The dashed line is a guide to the eye. Typical snapshot configurations of both phases are also shown, where the cultural state corresponding to the external message is indicated in white.

sets on, and, for large enough noise rates, the system becomes completely disordered. This behavior which was already reported in the absence of mass media interactions,¹⁴ is here also observed for $M > 0$. As we consider plots for increasing values of M , the transition between ordered and disordered states takes place for increasingly higher levels of noise. Indeed, this is an indication of the competition between noise rate and external field effects, thus showing that the external field induces order in the system.

Figure 2 shows the order-disorder phase diagram as a function of the field intensity and the number of traits per cultural attribute, for the noise rate $r = 10^{-3}$. The transition points correspond to $S_{\max}/L^2 = 0.5$. For the $M = 0$ case, noise-driven order-disorder transitions were found to be roughly independent of the number of traits per cultural attribute, as long as $q \geq 10$.¹⁴ Here, we observe a similar, essentially q -independent behavior for $M > 0$ as well. Typical snapshot configurations of both regions are also shown in Fig. 2, where the transition from the (small- M) multicultural regime to the (large- M) monocultural state is clearly observed. A majority of individuals sharing the same cultural state, identical to the external message, is found within the ordered phase. For smaller noise rates, $r \leq 10^{-4}$, the system is ordered even for $M = 0$, and hence only the monocultural phase is observed.

In order to gain further insight into the interplay and competition between cultural drift and mass media effects, let us now consider the external message being periodically switched on and off. Starting with a random disordered configuration and assuming a noise level above the transition value for the $M = 0$ case, we observe a periodical behavior: the system becomes ordered within the time window in which

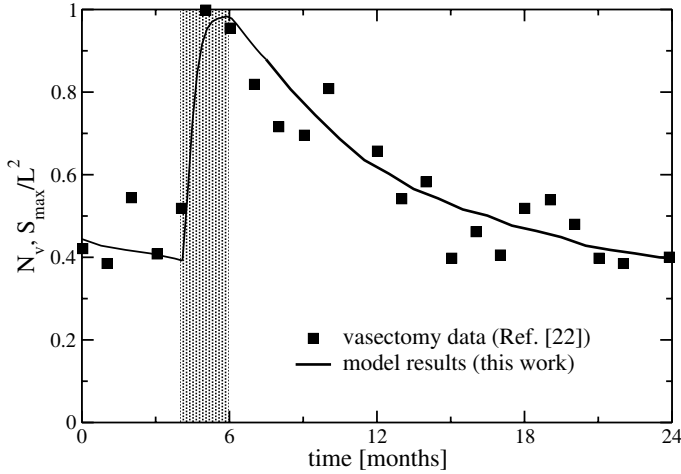


Fig. 3. Comparison of model predictions (solid line) to statistical data (symbols) measuring the impact of a mass media vasectomy promotion campaign in Brazil.¹⁹ The number of vasectomies per month, N_v , has been normalized and compared to the model's order parameter, S_{\max}/L^2 , while the time scales have been matched by setting 1 month = 500 MCS. The shaded region indicates the time window in which the mass media campaign was performed.

the field is applied, while it becomes increasingly disordered when the message is switched off. A cycle representing this behavior is shown by the solid line in Fig. 3, which corresponds to $r = 1.5 \times 10^{-4}$, $M = 10^{-2}$, and $q = 40$.

Moreover, we can compare this behavior to statistical data measuring the impact of a mass media vasectomy promotion campaign in Brazil.¹⁹ Symbols in Fig. 3 correspond to the number of vasectomies performed monthly in a major clinic in São Paulo, spanning a time interval of 2 years. The shaded region indicates the time window in which the mass media campaign was performed. The promotion campaign consisted of prime-time television and radio spots, the distribution of flyers, an electronic billboard, and public relations activities. In order to allow a comparison to model results, vasectomy data have been normalized by setting the maximal number of vasectomies measured equal to unity, while the relation between time scales has been chosen conveniently. In the model results, time is measured in Monte Carlo steps (MCS), where 1 MCS corresponds to L^2 iterations of the set of rules (1)–(3). For the comparison performed in Fig. 3, we assumed that 1 month corresponds to 500 MCS. Although the model parameters and scale units were arbitrarily assigned, it is reassuring to observe that a good agreement between observations and model results can be achieved. Indeed, the steep growth in the number of vasectomies practiced during the promotion campaign, as well as the monotonic decrease afterwards, can be well accounted for by this model.

In order to carry out a straightforward comparison between mass media effects in this model and the measured response within a social group, several simplifying assumptions were adopted. As commented above, the model parameters and scale

units were conveniently assigned. Moreover, no distinction was attempted between opinions (as modeled, within Axelrod's representation, by sets of cultural attributes in the mathematical form of vectors) and actual choices (as measured, e.g., by the vasectomy data shown in Fig. 3). In related contexts, analogous simplifying assumptions were adopted in the statistical physics modeling of political phenomena (e.g., the distribution of votes in elections in Brazil and India,²⁰⁻²² Italy and Germany,²³ four-party political scenarios,²⁴ etc), marketing competition between two advertised products,^{25,26} and applications to finance.²⁷

In summary, we have studied, in the context of an extension of Axelrod's model for social influence, the interplay and competition between cultural drift and mass media effects. The cultural drift is modeled by random perturbations, while mass media effects are introduced by means of an external field.

A noise-driven order-disorder transition is found. In the large noise rate regime, both the ordered (culturally polarized) phase and the disordered (culturally fragmented) phase can be observed, whereas in the small noise rate regime, only the ordered phase is present. In the former case, we have obtained the corresponding order-disorder phase diagram, showing that the external field induces cultural ordering. This behavior is opposite to that reported in Ref. 16 using a different prescription for the mass media field, which neglected the interaction between the field and individuals that do not share any features with the external message. Instead the mass media coupling proposed in this work is capable of affecting the cultural traits of any individual in the society.

In order to show the plausibility of the scenario considered here, we have compared the predictions of this model to statistical data measuring the impact of a mass media vasectomy promotion campaign in Brazil. A good agreement between model results and measured data can be achieved. The observed behavior is characterized by a steep growth during the promotion campaign, and a monotonic decrease afterwards. We can thus conclude that the extension of Axelrod's model proposed here contains the basic ingredients needed to explain the trend of actual observations.

We hope that the present findings will contribute to the growing interdisciplinary efforts in the mathematical modeling of social dynamics phenomena, and stimulate further work.

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