Competition of local and non-local interactions: Mass media effect in social dynamics

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Chapter 1

Introduction

1.1 Complexity and social sciences

The concept of complex systems has evolved from Chaos, Statistical Physics and other disciplines, and it has become a new paradigm for the search of mechanisms and a unified interpretation of the processes of emergence of structures, organization and functionality in a variety of natural and artificial phenomena in different contexts [1, 2, 3, 4, 5, 6]. The study of complex systems has become a problem of enormous common interest for scientists and professionals from various fields, including human sciences, leading to an intense process of interdisciplinary and unusual collaborations that extend and overlap the frontiers of traditional Science [7, 8, 9]. The use of concepts and techniques emerging from the study of complex systems and Statistical Physics has proven capable of contributing to the understanding of problems beyond the traditional boundaries of Physics.

Phenomena such as the spontaneous formation of structures, self-organization, spatial patterns, synchronization and collective oscillations, spiral waves, segregation and differentiation, formation and growth of domains, consensus phenomena [1, 2, 4, 5, 6, 10, 11, 12], are examples of emerging processes that occur in various contexts such as physical, chemical, biological, social and economic systems, etc. These effects are the result of interactions and synergetic cooperation among the elements of a system. The general concept of complex system has been applied to these sets of elements capable of generating global structures or functions that are absent at the local level. Understanding the complex collective behavior of many particles systems, in terms of macroscopic descriptions based in local interactions rules of evolution leading to the emergence of global phenomena, is a topic well established in Statistical Physics and it is relevant in the field of social science. An example of this micro-macro paradigm that show a close relationship between both sciences, Statistical physics and the Social Science, is Schelling's model of residential

segregation, that is mathematically equivalent to the zero-temperature spin-exchange Kinetic Ising model with vacancies [14].

The typical social system is composed of a high number of individuals that interact between them, showing nontrivial collective behaviors, such as nonequilibrium order-disorder transitions, emergence of collective phenomena, etc. This type of phenomena are the key for a qualitative and quantitative study from the point of view of Statistical Physics and complex systems [16]. In particular, the paradigm of complex systems in the context of social systems means that collective social structures emerge from the dynamic properties and interactions between individuals or elements in the system. In other words, we assume that many social phenomena are collective processes similar to those taking place in many nonequilibrium many body dynamical systems. In this regard, a variety of models have been proposed to explain the formation of structures from the interactions between agents of social systems. Most of these models have assumed that the local interaction rules can involve the simple imitation of a neighbor or an alignment to local majority (Ising-type). The main question concerns in all cases the possibility of the appearance of a global consensus, defined by the fact that all elements of the system have the same state or that a polarized states in which several coexistence states or opinions survive can be obtained. The parameters of the model drive transition between consensus and polarization.

Within this framework of the applications of the concepts of complex systems to social systems, there are a large number of physicists, economists, sociologists and experts in computer science who are studying social systems and characterizing mechanism involved in the processes of formation of opinion, cultural dissemination, spread of disease, formation of social networks of interaction. This has led to the establishment of links between various disciplines and to an increasing interdisciplinary collaboration between different areas of knowledge [8, 9, 17, 18, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31]

It may seem nonconventional that physicists are making dynamical models of social systems within the current context of complex systems. However, the attempt to try to explain social phenomena as any other physical phenomenon is not new. These ideas, somehow, were anticipated by several social thinkers of the nineteenth century. Auguste Comte, considered as the father of Sociology, was heavily influenced by Newtonian and Galilean Mechanics. He thought that Physics could apply to all natural phenomena, including the social phenomena. In his famous classification of sciences, Comte assumed that all scientific disciplines are eventually some kind of applications or branches of Physics. In this work, Comte distinguishes differences in Physics applications, separating them into two main areas: Inorganic Physics and Organic Physics. This separation also contains a list of different disciplines, such as, Celestial Physical (Astronomy), Terrestrial Physics (Geology);

Physiological Physics (Biology), etc.. In this scheme, there was room for Social Physics, which would be devoted to studying positively the social phenomena. Comte proposed to develop this science in his famous treaty Cours de Philosophie Positive [15]

The study of the interrelations among this interactive elements have revealed the existence of underlying networks of connections common in these systems [32, 33, 34, 30]. Thus, it has been found that systems as diverse as the World Wide Web, Internet, telecommunication networks, the spread of epidemics and computer viruses, dynamical social groups, economic corporations, insect colonies, metabolic flows in cells, neurons in the brain, physical systems, etc., show common network structures and share similar properties of self-organization. This topological structure in the interaction networks can be consider as the body of a complex system and are found in different context of the nature, from biological to social system. In this regard, the interaction in complex networks is a recent paradigm in statistical physics. [35].

This approach of statistical physics in the study of the network in social interaction have revealed the ubiquity of various striking characteristics, such as the small-world effect: although each node has a number of neighbors which remains small with respect to the total number of agents, only a small number of hops suffices to go from any agent to any other on the network. This has prompted the investigation of the effect of various interaction topologies on the behavior of agents connected according to these topologies, highlighting the relevance of small-world and heterogeneous structures [36, 37, 38]. More recently, the focus has shifted to take into account the fact that many networks, and in particular social networks interaction, are dynamical. In this case the links that connect a pair of elements in a system can be move or appear and disappear continuously in time, on many timescales. Moreover, such modifications of the networks topology do not occur independently from the nodes states but as a feedback effect: the topology determines the evolution of the agents opinions, which in its turn determines how the topology can be modified [19, 20, 21, 30, 40, 41]; the network becomes adaptive. In general, the network theory applied to complex social network and the macro-micro paradigm make possible an analysis of the effect of the topology of the network on a non-equlibrium dynamics as propose in order to understand the collective phenomena in a social system.

The addition of a global interaction to a locally coupled system is known to be able to induce phenomena not present in that system, such as chaotic synchronization and new spatial patterns[61, 62]. The classification and description of generic effects produced by external fields or global coupling in a nonequilibrium system of locally interacting units is still an open general question. The common wisdom for equilibrium systems is that under a strong

external field, local interactions become negligible, and the system orders following the external field. For nonequilibrium, nonpotential dynamics [13] this is not necessarily the case, and nontrivial effects might arise depending on the dynamical rules. This problem is, in particular, relevant for recent studies of social phenomena in the general framework of complex systems. In this work we address this problem in the context of mass media effects in cultural dynamics.

Several mathematical models, many of them based on discrete-time and discrete-space dynamical systems, have been proposed to describe a variety of phenomena occurring in social dynamics [23, 24, 25, 26, 27, 28, 29, 30, 31]. Specially interesting is the lattice model introduced by Axelrod [42] to investigate the dissemination of culture among interacting agents in a society [46, 43, 31, 47, 51, 49, 52, 48]. The state of an agent in this model is described by a set of individual cultural features. The local interaction between neighboring agents depends on the cultural similarities that they share and similarity is enhanced as a result of the interaction. From the point of view of statistical physics, this model is appealing because it exhibits a nontrivial out of equilibrium transition between an ordered phase (a homogeneous culture) and a disordered (multicultural) one, as in other well studied lattice systems with phase ordering properties [39]. The additional effect of global coupling in this system has been considered as a model of influence of mass media [43]. It has also been shown that the addition of external influences, such as random perturbations [49] or a fixed field [53], can induce new order-disorder nonequilibrium transitions in the collective behavior of Axelrod's model. However, a global picture of the results of the competition between the local interaction among the agents and the interaction through a global coupling field or an external field is missing. Here we consider this general question in the specific context of Axelrod's model.

We deal with states of the elements of the system and interacting fields described by vectors whose components can take discrete values. The interaction dynamics of the elements among themselves and with the fields is based on the similarity between state vectors, defined as the fraction of components that these vectors have in common. We consider interaction fields that originate either externally (an external forcing) or from the contribution of a set of elements in the system (an autonomous dynamics) such as global or partial coupling functions. Our study allows to compare the effects that driving fields or autonomous fields of interaction have on the collective properties of systems with this type of nonequilibrium dynamics. In the context of social phenomena, our scheme can be considered as a model for a social system interacting with global or local mass media that represent endogenous cultural influences or information feedback, as well as a model for a social system subject to an external cultural influence.

1.2 Outline

The outline of this work is as follows: In Chapter 2 we introduce Axelrod's model describing cultural dissemination [42]. We present the formal definition, general properties and the most important previous results on the model. In Chapter 3, we study the effects of mass media modeled as applied fields on a social system based on Axelrod's model. We define different types of fields: a *constant external field*, a *global field* and a *local field*. These fields represent influences of different types of mass media. The effects of these fields will be analyzed in both the order and disorder phases of the system. In Chapter 4, we study another mechanism of interaction with mass media fields, introduced by Shibanai et al. [43]. Indirect mass media influence is defined, as a global field acting like a filter of the influence of the existing network of interactions of each agent. In Chapter 5 we present our conclusion and point to directions for future research.

Chapter 2

Axelrod's model for the dissemination of culture

In an seminal paper, Robert Axelrod [42] addressed the question:

" if people tend to become more alike in their beliefs, attitudes, and behavior when they interact, why do not all differences eventually disappear ? "

To investigate this problem, Axelrod introduced an agent-based model to explore mechanisms of competition between the tendency towards globalization and the persistence of cultural diversity. These mechanism seeks to sketch in broad outline how cultures and customs are disseminated in the society. Culture in this model is defined as a set of individual attributes subject to social influence. Thus, the model assumes that an individual's culture can be described in terms of his or her attributes such as language, religion, technology, style of dress and so forth. This definition describes a culture as list of features or culture dimension. For each feature there is a set of traits, which are the alternative values the feature may have. For example, one feature of a culture could be the religious belief, and the traits represents of different choices for this feature, such as Buddhism, Atheism or Christianity. It is important to indicate that the emphasis of this work is not on the content of a specific culture, but rather on the way in which a culture is likely to emerge and spread.

Within this framework, the local interaction between neighboring agents follows two basic social principles that are believed to be fundamental in the understanding of the dynamics of cultural assimilation (and diversity): social influence and homophily. The first is the tendency of individuals to be more similar when they interact. The second is the tendency of likes to attract each other, so that they interact more frequently. In other words, these principles mean that the probability that two individuals interact is proportional to the

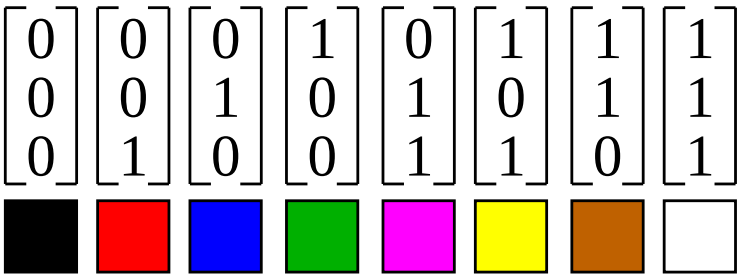

Figure 2.1: Color code for $F = 3$ and $q = 2$.

cultural overlap between the agents, that is, to the amount of cultural similarities (number of features) that they share and the similarity is enhanced when interaction occurs. With these two ingredients Axelrod show that the system can freeze in a multicultural state with coexisting spatial domains with different cultures, illustrating how a simple mechanism of local convergence can lead to global polarization.

2.1 Presentation of the model

The Axelrod model consists of a set of N agents located at the nodes of an interaction network. The state of an agent i is given by an F-component vector C_i^f $(f = 1, 2, \ldots, F)$. In this model, the F components of vector C_i^f correspond to the culture features (language, religion, etc.) describing the F-dimensional culture of agent i. Each component of the cultural vector of i can take any of the q values in the set $\{0, 1, \ldots, q-1\}$ (called cultural traits in Axerlrod's model). As an initial condition, each agent i is randomly and independently assigned on of the q^F possible state vectors with uniform probability. In the model, all q^F possible states are equivalent.

Starting from a random initial condintion, the discrete-time dynamics of the system is defined by interacting the following steps:

1. Select at random a pair of sites of the network connected by a bond (i, j).
2. Calculate the overlap (number of shared features) $l(i, j) = \sum_{f=1}^{F} \delta_{C_i^f, C_j^f}$.
3. If $0 < l(i, j) < F$, the bond is said to be active and sites i and j interact with probability $l(i, j)/F$. In case of interaction, choose g randomly such that $C_i^g \neq C_j^g$ and set $C_i^g = C_j^g$.

After N such update events, time is increased by 1.

From view point of statistical physicists, the Axelrod model is a simple and natural *vector* generalization of models of opinion dynamics that gives

rise to a very rich and nontrivial phenomenology, with some genuinely novel behavior that has attracted a lot of interest from physicist.

In the next section, we will summarize the most important results of this model.

2.2 Summary of previous results

In the last years, systematic studies of Axelrod's model have identified a globalization-polarization transition depending on the value of q for a fixed F [46, 31, 48, 49]. These works have shown that the system reaches an stationary configuration in any finite network, where for any pair of neighbors i and j, $l(i,j) = 0$ or $l(i,j) = F$. Homogeneous or ordered states (globalization) correspond to $l(i,j) = F$, $\forall i,j$, this means that all the sites have the same value of cultural trait for each feature. Obviously there are q^F possible configurations of this state. Inhomogeneous or disordered states (global polarization) consist of the coexistence of several domains, where a domain is defined as a set of connected nodes with the same cultural vector state. The number of domain is taken as measure of cultural diversity.

For the visualization of state of the system to each cultural state is assigned a color (see figure 2.1), thus we can identify a cultural domain with a given color. Figure 2.2, shows a example of a typical simulation of Axelrod's model in a two-dimensional network in $t = 0$ and in the asymptotic cultural configurations ($t = \infty$), for $F = 10$ and two values of q ($q = 5$ and $q = 60$) as initial condition (see reference [65]). For small value of q ($q = 5$) the system reaches a globalization state (see top right of figure 2.2) where all nodes form a single domain (blue color), indicating that all individuals same time, have the same cultural state, while for $q = 60$, the system freeze in an absorbing multicultural state where different cultural domains coexist, illustrating how the local convergence can induce a global polarization.

In order to characterized the ordering properties of this system, the normalized average size of largest domain $\langle S_{max}\rangle/N$ formed in the system, is defined as order parameter. For any finite networks the dynamics displays a critical point q_c that separates two phases: an ordered phase or monocultural state ($\langle S_{max}\rangle/N \simeq 1$) for $q < q_c$, and an disordered phase or multicultural state ($\langle S_{max}\rangle/N \ll 1$) for $q > q_c$ [46, 50, 51, 49, 52, 48, 53, 54, 55].

In two-dimensions, the kind of the transition depends on the value of F [46, 51, 48, 53]. When $F > 2$ the transition is of first order, with the size of the largest domain having a finite discontinuity as shown the figure 2.3. In this figure we plot the order parameter $\langle S_{max}\rangle/N$ as function of q for a two-dimensional network and $F = 10$. Here we identify a threshold $q = q_c \approx 55$ where occurs the order-disorder transition. When $q < q_c$ the order parameter $\langle S_{max}\rangle/N \simeq 1$ (see top right of figure 2.2), while for $q > q_c$, $\langle S_{max}\rangle/N \simeq\ll 1$

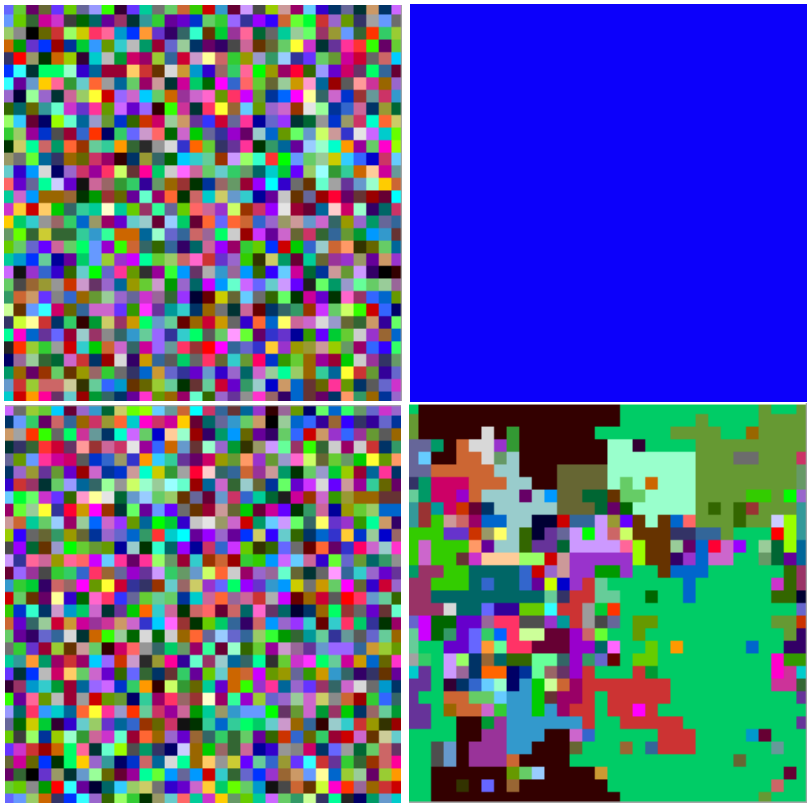

Figure 2.2: State of the system in $t = 0$ (left) and $t = \infty$ (right), $F = 10$, $q = 5$ (top), $F = 10$, $q = 60$ (bottom). System size $N = 64$ [65].

(see bottom right of figure 2.2). This figure also shows that the transition at the critical point ($q = q_c$) becomes sharper as the system size increases, so that in the thermodynamics limit the transition is well defined (see figure 2.3). However, the situation for $F = 2$ is different, in this case the order parameter $\langle S_{max} \rangle / N$ vanishes continuously as $q \longrightarrow q^-$ (see reference [46]). In one-dimension, the nature of the transition change, the dynamic displays a second order transition [48].

Analytical approaches have also been considered for this model. A mean field approach of this model have been treated by Castellano et al. [46] and F. Vazquez & Redner [50]. This approach consists in writing down rate equations for the densities P_m of bonds of type m. These are bonds between interaction partners that have m common features. The natural order parameter in this case is the density of active links $n_a = \sum_{m=1}^{F-1} P_m$, where a link is active if $0 \leqslant m \leqslant F - 1$. This order parameter is zero in the disordered phase, while it is finite larger that zero in the ordered phase. This approach gives a discontinuous transition for any F. In the particular case of $F = 2$ the mean field equations can be studied analytically in detail by Vazquez and Redner

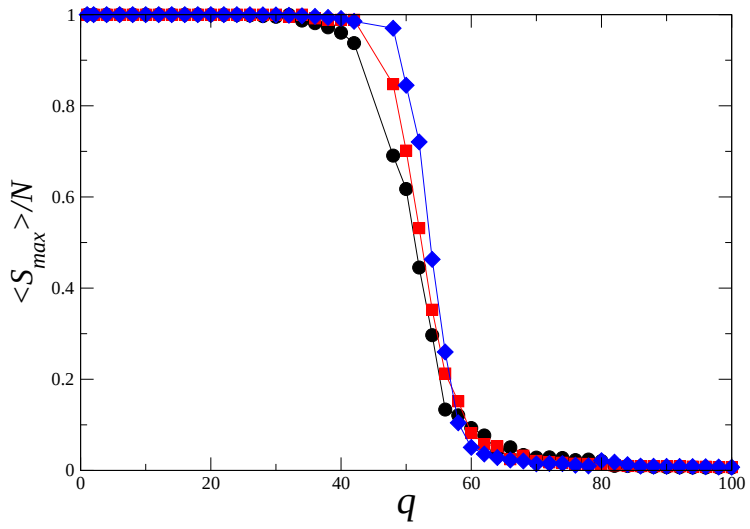

Figure 2.3: Average size of the largest cultural domain $\langle Smax \rangle / N$ vs q for $F = 10$ features and system sizes $N = 900$ (circles), $N = 1600$ (squares) and $N = 2500$ (diamonds). The transition at the critical point $q_c \simeq 55$ becomes sharper as the system size increases.

[50], providing insight into the non-monotonic dynamic behavior for $q \lesssim q_c$ and showing that the approach to the steady state is governed by a time scale diverging as $\mid q - q_c \mid^{-1/2}$.

A number of works have addressed the issue of the role of social network of interaction. The Axelrod model has been studied on small-world (SW)(Klemm et al., [51]) and scale-free networks Barabasi-Albert (AB)(Klemm et al., [51]) In the first case, the transition between consensus and a disordered multicultural phase is still observed, for values of the control parameter q_c that grow as a function of the rewiring parameter p. Therefore, this work shows that the non-local connectivity favors cultural globalization as described by the ordered state, as shown in figure 2.4, where the order parameter $\langle S_{max} \rangle / N$ is plotted as function of q for different values of p. Since the SW network for $p = 1$ is a random network this is consistent with the observation of the transition also in the mean field approaches made by Castellano et al. 2000 [46] and Vazquez and Redner 2007 [50]. In the second case, for the scale-free network, the behavior of the systems dramatically changes the picture. For a given network size N, the system also displays a transition order-disorder for an effective value of $q = q_c$. However the critical point where occurs the transition grows with N as $q_c \sim N^{0.39}$ (see figure 2.5), so that in the thermodynamic limit the transition disappears and only ordered states are possible.

Recently, Axelrod's model also has been studied in a co-evolution network [9, 56]. This model combines the traditional mechanisms of homophily and social influence with a third mechanism of network homophily, in which net-

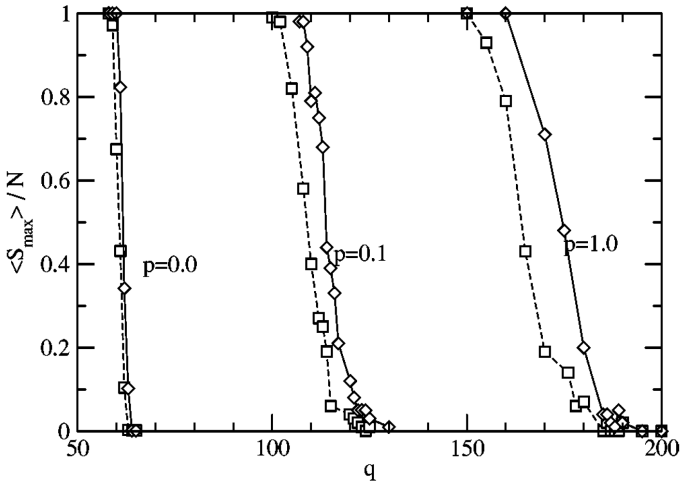

Figure 2.4: Average size of the fraction of the largest cultural domain $\langle Smax \rangle / N$ vs q for three different values of the small-world parameter p. System sizes $N = 500^2$ (squares) and $N = 1000^2$ (diamonds); number of features $F = 10$. From ([51])

work structure co-evolves with cultural interaction. Here, the individuals cut their ties with incompatible partners and form new ties with other like-minded individuals. In this model the structure of the network changes over time as response of the state of nodes and vice versa. This system displays two transitions that depends of value of q for a fixed F. The first one is an order-disorder transition at $q = q_c$ between two frozen phases, associated with the fragmentation of the network. The dynamics leads to the formation of network components, where component is defined here as a set of connected nodes. In a frozen configuration agents that belong to the same component have the same state. For $q < q_c$ (order phase), the system reaches a configuration composed by a giant component of the order of the system size, and a set of small components, while for $q > q_c$ (disorder phase) the large component disintegrates in many small disconnected components. The second transition, is related with network recombination and occurs at $q = q^*$ between the disorder phase and an active phase, where the system reaches a dynamic configuration with links that are permanently rewired. In this active phase, there are a only one component where different cultural states coexist. In these works it also shown that the fragmentation is a consequence of the competition between two coupled mechanism, network dynamics and the state formation, that are governed by two internal time associated with the evolution of the network interaction and the dynamics of states, which are not controlled by external parameter, but that emerge from the dynamics of the system [56].

Apart from of the study of the topology of interactions, other extensions of this model have been investigated. Some of them already suggested in

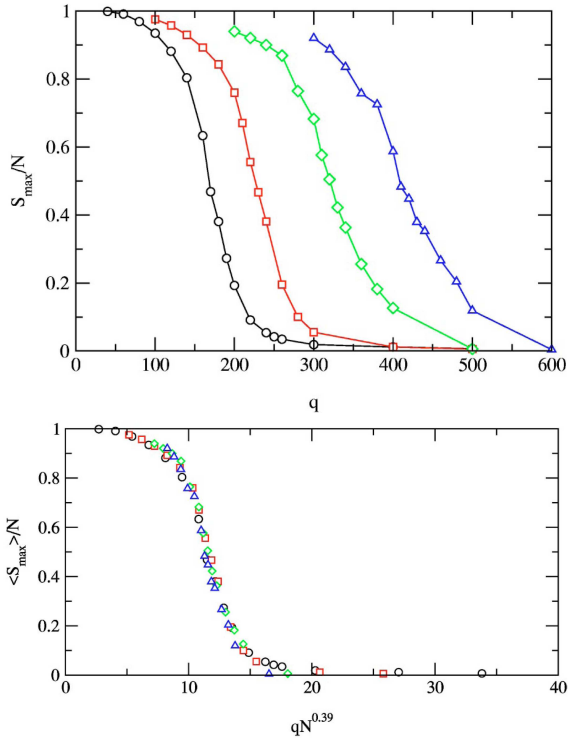

Figure 2.5: *Top*: The average order parameter $\langle S_{max} \rangle / N$ in scale free networks for $F = 10$. Different curves are for different system size: 1000 (circles), 2000 (squares), 5000 (diamonds) and 10,000 (triangles). *Bottom*: Rescale plot of the data shown in top of this figure for different system size. From ([51])

Axelrod'ssuch as is the study of cultural drift. In references [49, 52], the cultural drift is modeled as spontaneous change in a trait of a one of the features of a node. These changes can be interpreted as a type of noise acting on the system. The perturbation consist in randomly choosing $i \in \{1, ..., N\}$, $f \in \{1, ..., F\}$ and $s \in \{1, ..., q\}$ and setting $C_i^f = s$. This rule is implemented by including a fourth step in the interacted loop of the Axelrod's model.

4. With probability r, perform a single perturbation.

In these works, it is demostrated that noise (cultural drift) induces an order-disorder transition independently of value of q, as shown in figure 2.6. In this figure, the effective noise rate $r' = r(1 - 1/q)$, is considered as control parameter. We observe that all curves collapse into a single curve, showing that independently of the values of the parameter q, the system displays the same behavior. This curve identifies, for a fixed size of the system, a continuous order-disorder transition controlled by the noise rate r. For small noise rate the state of the system is monocultural. This occurs because disordered configurations are unstable with respect to the perturbation introduced by

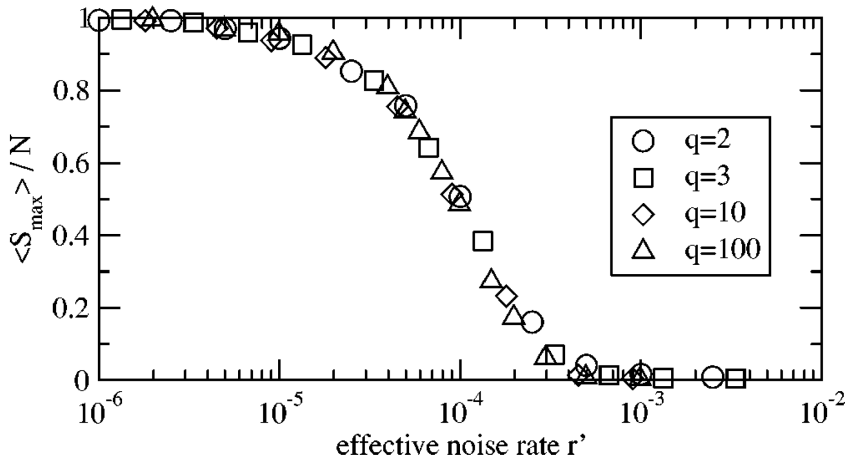

Figure 2.6: $\langle S_{max} \rangle / N$ as function of the effective noise rate $r' = r(1-1/q)$ for different values of q. System size $N = 50^2$ with $F = 10$. From [49]

the noise. However, when the noise rate is large, the disappearance of domains is compensated by the rapid formation of new ones, so that the steady state is disordered. For a finite system, the ordered state of the system under action of small perturbations, is not a fixed homogeneous configuration. During long time scales, the system visits a series of monocultural configuration. The threshold between the two behaviors is set by the inverse of the average relaxation time for a perturbation $T(N)$, so that the transition occurs for $r_c T(N) = O(1)$. An approximate evaluation of the relaxation in $d = 2$ gives $T = Nln(N)$, in good agreement with simulations, while $T \sim N^2$ on one dimension [49, 52], Therefore, no matter how small the rate of cultural drift is, in the thermodynamic limit the system remains always disordered for any q.

Other extensions include the consideration of quantitative instead of qualitative values for the cultural traits (Flache and Macy, 2006 [57]), the extension of the model to continuous values of the cultural traits and the inclusion of heterophobic interactions (Macy et al., 2003 [58]), the simulation of technology assimilation (Leydesdorff, 2001 [59]) and the consideration of specific historical contexts (Bhavnani, 2003 [60]).

Within this general context of different forms of social interactions, the influence of mass media on the system has also been considered [43, 44, 45, 53, 54, 55]. In these works, mass media are modeled as different types of fields. A mass media cultural message is described as a vector M that can interact with each node in the system. The vector field M may be of different nature. For example, Shibanai et al. [43], study the effect of a global mass media influence interpreted as a kind of global information feedback acting on the system. In this case, mass media is represented by a global field vector which contains the most predominant trait in each cultural feature present in a society. In

this work [43] two mechanisms for the interaction with the global field have been considered. In the first one, the field has the same influential power as a real neighbor, in the second one, the neighbors are influential only when their traits are concordant with the trait of the global vector field. In this case the global information feedback acts as filter of local neighbor's influence. The intensity of the fields or the mass media influence is controlled by an external parameter. The conclusion of this work, somehow counterintuitive, is that global information feedback facilitates the maintenance of cultural diversity. However, Shibanai et al., restrict the study of global mass media interaction to a single value of q in the ordered phase. In this work we investigate the general problem of the effect of different mass media, and for different values of q [54, 55]. Other recent related works deal with a version Axerlrod's model with both an external field and noise in a two-dimensional network and in social networks with community [44, 45].

Chapter 3

The Axelrod's Model with global, local and external field interaction: Mass media effects

In this Chapter we address the general question of the effects of different types of mass media influences on cultural dynamics in the context of Axelrod's model. Here the mass media is modeled as field interaction applied on the system. This extension was referred to as "public education and broadcasting" [42]. Our aim is to identify the mechanisms, and their efficiency, by which mass media modifies processes of cultural dynamics based on local agent interactions. To answer these questions, we consider mass media influences that originate either externally or endogenously, and that the agent-agent interaction and interaction of the agents with the mass media is based on the same homophily and social influence principles of Axelrod model. For the case the endogenous mass media interaction, our scheme is a model for social systems interacting with global or local mass media that represents plurality information feedback at different levels.

3.1 The model

The system consists of N elements as the sites of a square lattice. The state of an agent i is given by an F-component vector C_i^f $(f = 1, 2, \ldots, F)$. In this model, the F components of vector C_i^f correspond to the culture features (language, religion, etc.) describing the F-dimensional culture of agent i. Each component of the cultural vector of i can take any of the q values in the set $\{0, 1, \ldots, q-1\}$ (called cultural traits in Axerlrod's model). As an initial condition, each agent i is randomly and independently assigned on of the q^F possible state vectors with uniform probability. We introduce a vector field M with components $(\mu_{i1}, \mu_{i2}, \ldots, \mu_{iF})$. Formally, we treat the field at each ele-

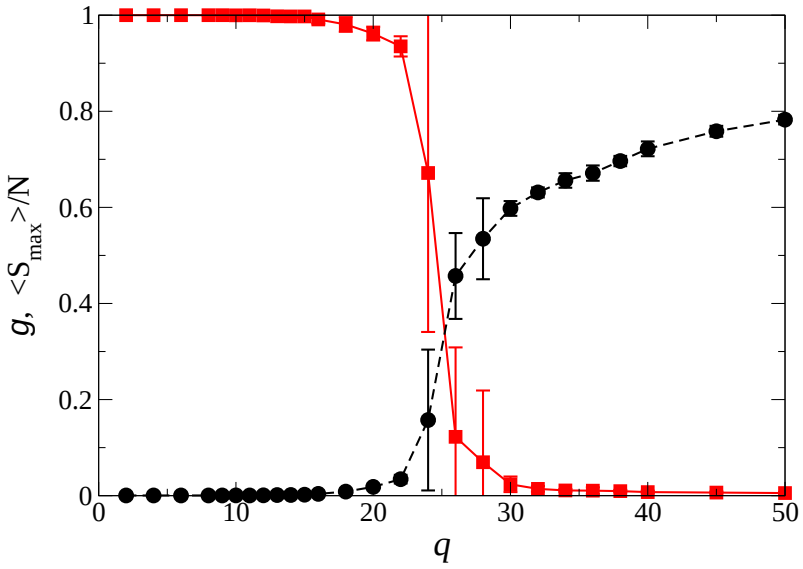

Figure 3.1: Order parameters g (circles) and $\langle S_{max}\rangle/N$ (squares) as a function of q, in the absence of a field $B = 0$.

ment i as an additional neighbor of i with whom an interaction is possible. The field is represented as an additional element $\phi(i)$ such that $C^f_{\phi(i)} = \mu_{if}$ in the definition given below of the dynamics. The strength of the field is given by a constant parameter $B \in [0, 1]$ that measures the probability of interaction with the field. The system evolves by iterating the following steps:

(1) Select at random an element i on the lattice (called active element).

(2) Select the source of interaction j. With probability B set $j = \phi(i)$ as an interaction with the field. Otherwise, choose element j at random among the four nearest neighbors (the von Neumann neighborhood) of i on the lattice.

(3) Calculate the overlap (number of shared components) $l(i, j) = \sum_{f=1}^{F} \delta_{C^f_i, C^f_j}$. If $0 < l(i, j) < F$, sites i and j interact with probability $l(i, j)/F$. In case of interaction, choose g randomly such that $C^g_i \neq C^g_j$ and set $C^g_i = C^g_j$.

(4) Update the field M if required (see definitions of fields below). Resume at (1).

Step (3) specifies the basic rule of a nonequilibrium dynamics which is at the basis of most of our results. It has two ingredients: i) A similarity rule for the probability of interaction, and ii) a mechanism of convergence to an homogeneous state.

In order to characterize the ordering properties of this system, we consider as an order parameter the average fraction of cultural domains $g = \langle N_g\rangle/N$. Here N_g is the number of domains formed in the final state of the system for a given realization of initial conditions. Figure 3.1 shows the quantity g as a function of the number of options per component q, for $F = 5$, when no field

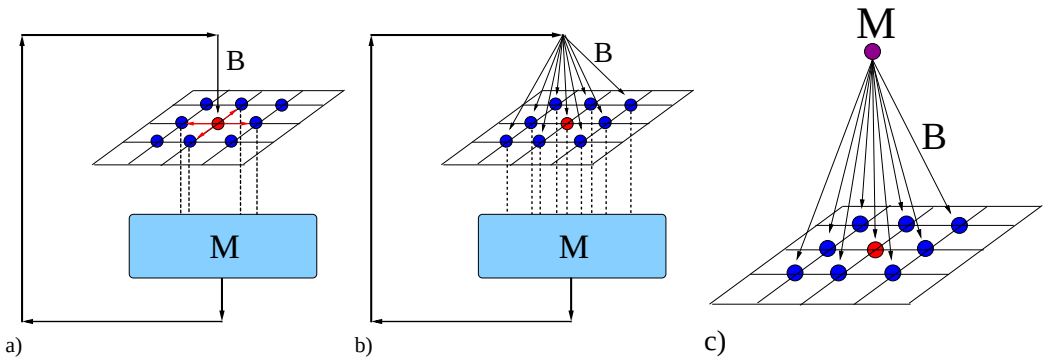

Figure 3.2: Diagrams representing the different types of mass media influences acting on the system. a) Global mass media. b) Local mass media. c) External mass media

acts on the system ($B = 0$). For values of $q < q_c \approx 25$, the system always reaches a homogeneous state characterized by values $g \to 0$. On the other hand, for values of $q > q_c$, the system settles into a disordered state, for which $\langle N_g \rangle \gg 1$. Another previously used order parameter, as described in Chapter 2 [46, 51], the average size of the largest domain size, $\langle S_{\max} \rangle / N$, is also shown in Fig. 3.1 for comparison. In this case, the ordered phase corresponds to $\langle S_{\max} \rangle / N = 1$, while complete disorder is given by $\langle S_{\max} \rangle / N \to 0$. Unless otherwise stated, our numerical results throughout the paper are based on averages over 50 realizations for systems of size $N = 40 \times 40$, and $F = 5$.

Let us now consider the case where the elements on the lattice have a non-zero probability to interact with the field ($B > 0$). We distinguish three types of fields.

(i) The *external field* is spatially uniform and constant in time. Initially for each component f, a value $\epsilon_f \in \{1, \ldots, q\}$ is drawn at random and $\mu_{if} = \epsilon_f$ is set for all elements i and all components f. It corresponds to a constant, external driving field acting uniformly on the system. A constant *external field* can be interpreted as a specific cultural state (such as advertising or propaganda) being imposed by controlled mass media on all the elements of a social system [53].

(ii) The *global field* is spatially uniform and may vary in time. Here μ_{if} is assigned the most abundant value exhibited by the f-th component of all the state vectors in the system. If the maximally abundant value is not unique, one of the possibilities is chosen at random with equal probability. This type of field is a global coupling function of all the elements in the system. It provides the same global information feedback to each element at any given time but its components may change as the system evolves. In the context of cultural models [43], this field may represent a global mass media influence shared identically by all the agents and which contains the most predominant trait

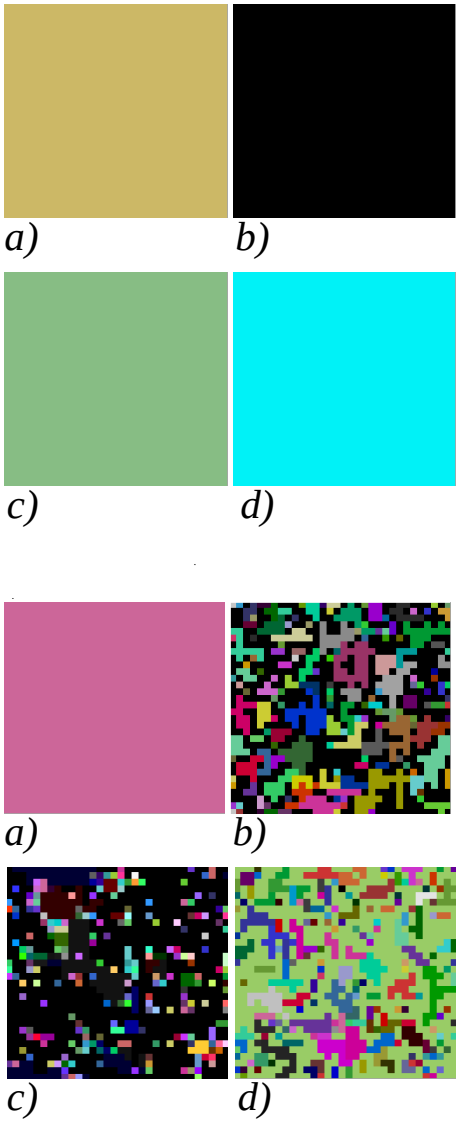

Figure 3.3: Asymptotic configurations of the Axelrod's model with mass media influence, for $F = 5$, $q = 10$, and $N = 32 \times 32$. *Top panel* corresponds the numerical simulation for $B = 0.0045 < B_c$. *Bottom panel* corresponds to the numerical simulation for $B = 0.5 > B_c$. $a)$ Absence of field interaction, $b)$ External field, $c)$ Local field, $d)$ Global field. The vector field in the case of external interaction is identified with the black color [65].

in each cultural feature present in a society (a "global cultural trend").

(iii) The *local field*, is spatially non-uniform and non-constant. Each component μ_{if} is assigned the most frequent value present in component f of the state vectors of the elements belonging to the von Neumann neighborhood of element i. If there are two or more maximally abundant values of component f one of these is chosen at random with equal probability. The *local field* can

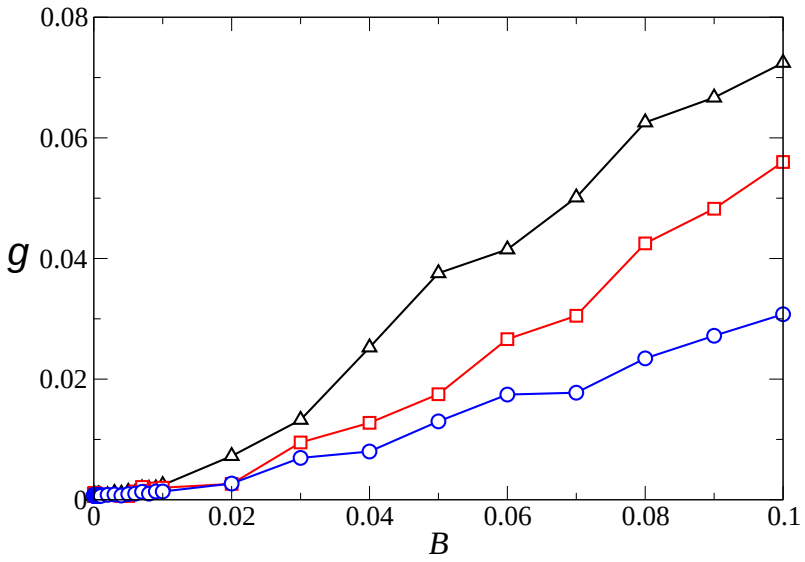

Figure 3.4: Order parameter g as a function of the coupling strength B of an *external* (squares), *global* (circles) and *local* (triangles) *field*. Parameter value $q = 10 < q_c$.

be interpreted as local mass media conveying the "local cultural trend" of its neighborhood to each element in a social system.

Case (i) corresponds to a driven spatiotemporal dynamical system. On the other hand, cases (ii) and (iii) can be regarded as autonomous spatiotemporal dynamical systems. In particular, a system subject to a *global field* corresponds to a network of dynamical elements possessing both local and global interactions. Both the constant *external field* and the *global field* are uniform. The *local field* is spatially non-uniform; it depends on the site i. In the context of cultural models, systems subject to either *local* or *global fields* describe social systems with endogenous cultural influences, while the case of the *external field* represents and external cultural influence.

Cultural influences generated endogenously represent a plurality information feedback, which is one of the functions of mass media [43], but this can occur at a global ("broadcast") or at a local ("narrowcast") level.

The strength of the coupling to the interaction field is controlled by the parameter B. We shall assume that B is uniform, i.e., the field reaches all the elements with the same probability. In the cultural dynamics analogy, the parameter B can be interpreted as the probability that the mass media vector has to attract the attention of the agents in the social system. The parameter B represents enhancing factors of the mass media influence that can be varied, such as its amplitude, frequency, attractiveness, etc. The different types of field or mass media influences are schematically shown in Fig. 3.2.

Simulations of the model described here for different values of parameters,

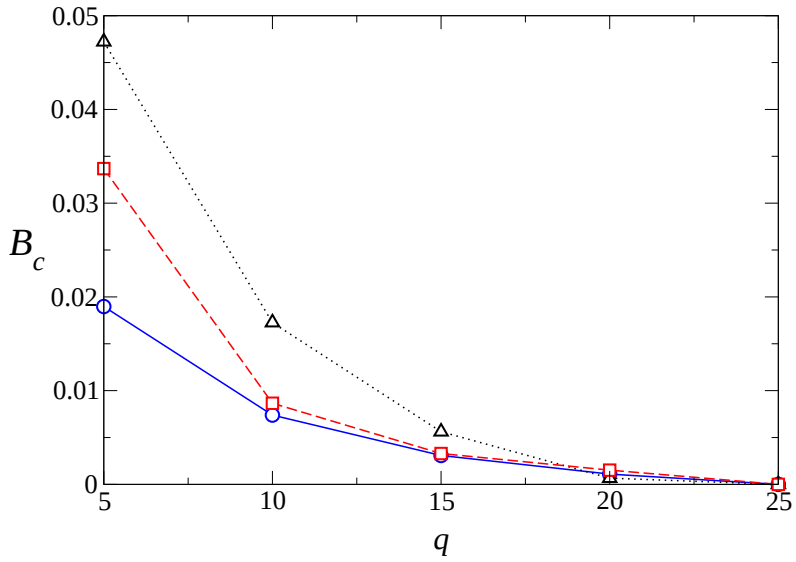

Figure 3.5: Threshold values B_c for $q < q_c$ corresponding to the different fields. Each line separates the region of order (above the line) from the region of disorder (below the line) for an *external* (squares), *global* (circles), and *local* (triangles) *field*.

can be accessed on-line (http://ifisc.uib-csic.es/research/APPLET_Axelrod/Culture.html) trough a Java Applet.

3.2 Effects of an interacting Field for $q < q_c$

In the absence of any interaction field, the system settles into one of the possible q^F homogeneous states for $q < q_c$ (see Fig. 3.1). However, when the interaction with a field is added, the behavior is affected as shown in the numerical simulation of the figure 3.3. This figure, shows the asymptotic configurations of the system for the different fields and two values of B in the ordered phase ($q < q_c$). For the case $B = 0.0045$ the system reaches a homogeneous state, while for $B = 0.5$, independently of the nature of the field, the system displays a disordered state. This results suggest that there is a threshold in the intensity of the applied field on the system for which the mass media induce disorder.

A systematic study of this behavior, the figure 3.4 shows the order parameter g as a function of the coupling strength B for the three types of fields. When the probability B is small enough, the system still reaches in its evolution a homogeneous state ($g \to 0$) under the action of any of these fields. In the case of an *external field*, the homogeneous state reached by the system is equal to the field vector [53]. Thus, for small values of B, a constant *external field* imposes its state over all the elements in the system, as one may

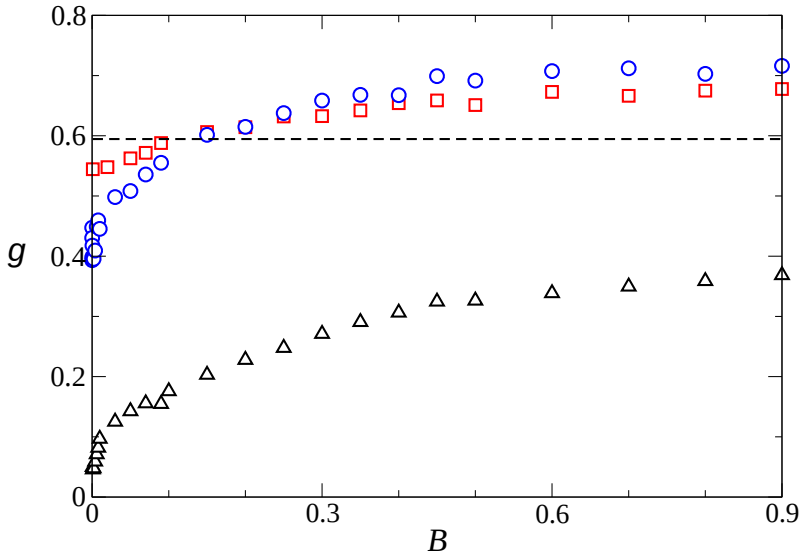

Figure 3.6: Order parameter g as a function of the coupling strength B of an *external* (squares), *global* (circles) and *local* (triangles) *field*. The horizontal dashed line indicates the value of g at $B = 0$. Parameter value $q = 30$.

expect. With a *global* or with a *local field*, however, for small B the system can reach any of the possible q^F homogeneous states, depending on the initial conditions. Regardless of the type of field, there is a transition at a threshold value of the probability B_c from a homogeneous state to a disordered state characterized by an increasing number of domains as B is increased. Thus, we find the counterintuitive result that, above some threshold value of the probability of interaction, a field induces disorder in a situation in which the system would order (homogeneous state) under the effect alone of local interactions among the elements. The same behavior is reported by Shebanai et al. for the case of a global field [43].

The threshold values of the probability B_c for each type of field, obtained by a regression fitting [53], are plotted as a function of q in the phase diagram of Fig. 3.5. The threshold value B_c for each field decreases with increasing q for $q < q_c$. The value $B_c = 0$ for the three fields is reached at $q = q_c \approx 25$, corresponding to the critical value in absence of interaction fields observed in Fig. 3.1. For each case, the threshold curve B_c versus q in Fig. 3.5 separates the region of disorder from the region where homogeneous states occur on the space of parameters (B, q). For $B > B_c$, the interaction with the field dominates over the local interactions among the individual elements in the system. Consequently, elements whose states exhibit a greater overlap with the state of the field have more probability to converge to that state. This process contributes to the differentiation of states between neighboring elements and to the formation of multiple domains in the system for large enough values of

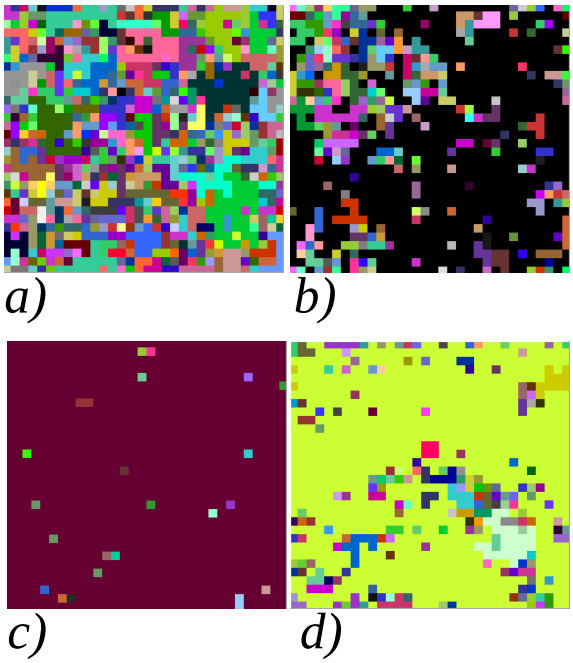

Figure 3.7: Asymptotic configurations of the Axelrod's model with mass media influence, for $F = 5$, $q = 10$, $N = 32 \times 32$ and $B = 0.0045$. $a)$ Absence of field interaction, $b)$ External field, $c)$ Local field, $d)$ Global field. The vector field in the case of external interaction is identify with the black color [65].

the probability B.

Note that the region of homogeneous ordered states in the (B, q) space in Fig. 3.5 is larger for the *local field* than for the *external* and the *global fields*. A nonuniform field provides different influences on the agents, while the interaction with uniform fields is shared by all the elements in the system. The *local field* (spatially nonuniform) is less efficient than uniform fields in promoting the formation of multiple domains, and therefore order is maintained for a larger range of values of B when interacting with a *local field*.

3.3 Effects of an interacting Field for $q > q_c$

When there are no additional interacting fields ($B = 0$), the system always freezes into disordered states for $q > q_c$ (see Fig. 3.1). Figure 3.6 shows the order parameter g as a function of the probability B for the three types of fields. The effect of a field for $q > q_c$ depends on the magnitude of B. In the three cases we see that for $B \to 0$, g drops to values below the reference line corresponding to its value when $B = 0$. Thus, the limit $B \to 0$ does not recover the behavior of the model with only local nearest-neighbor interactions.

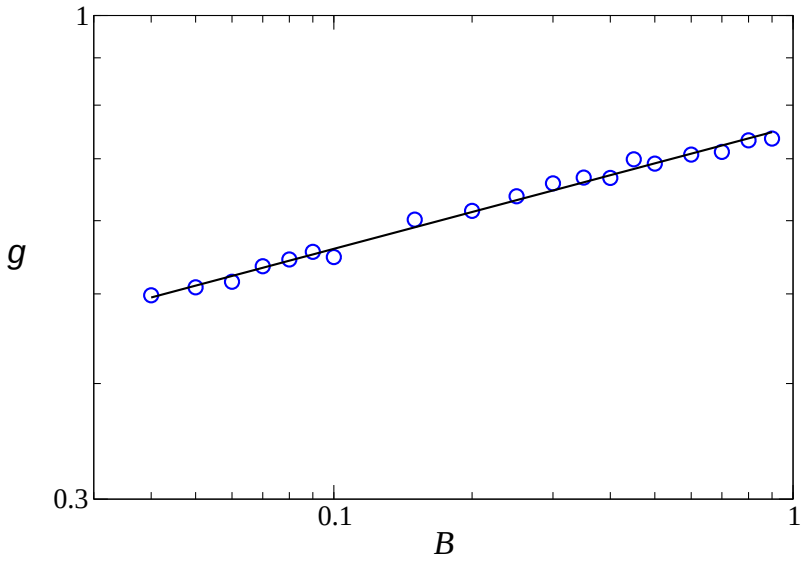

Figure 3.8: Scaling of the order parameter g with the coupling strength to the *global field* B. The slope of the fitting straight line is $\beta = 0.13 \pm 0.01$. Parameter value $q = 30 > q_c$.

The fact that for $B \to 0$ the interaction with a field increases the degree of order in the system is related to the non-stable nature of the inhomogeneous states in Axelrod's model. When the probability of interaction B is very small, the action of a field can be seen as a sufficient perturbation that allows the system to escape from the inhomogeneous states with frozen dynamics. A example of this behavior is observed in the figure 3.7, that shows the spatial configurations of the final states of the systems under the influence of a field in the disordered state ($q > q_c$). In the numerical simulation, we observe that a weak interaction with the field can induce order in the system. This effect is similar independently of the source of the field, however, the local field is more efficient to order the system, while the external field interaction is less efficient to induce order in the system. The role of a field in this situation is similar to that of noise applied to the system, in the limit of vanishingly small noise rate [49].

The drop in the value of g as $B \to 0$ from the reference value ($B = 0$) that takes place for the *local field* in Fig. 3.6 is more pronounced than the corresponding drops for uniform fields. This can be understood in terms of a greater efficiency of a nonuniform field as a perturbation that allows the system to escape from a frozen inhomogeneous configuration. Increasing the value of B results, in all three types of fields, in an enhancement of the degree of disorder in the system, but the *local field* always keeps the amount of disorder, as measured by g, below the value obtained for $B = 0$. Thus a *local field* has a greater ordering effect than both the global and the *external field*s

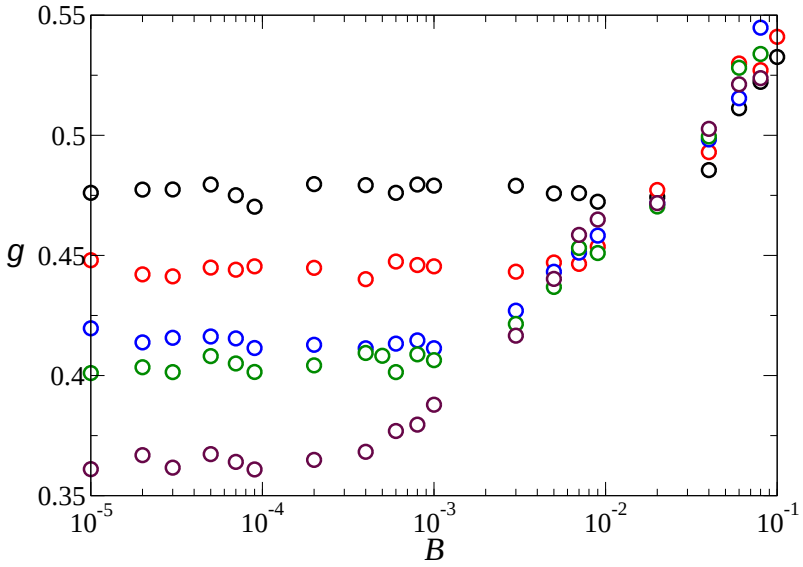

Figure 3.9: Finite size effects at small values of the strength B of a *global field*. Order parameter g as a function of B is shown for system sizes $N = 20^2, 30^2, 40^2, 50^2, 70^2$ (from top to bottom). Parameter value $q = 30$.

for $q > q_c$.

The behavior of the order parameter g for larger values of B can be described by the scaling relation $g \sim B^\beta$, where the exponent β depends on the value of q. Figure 3.8 shows a log-log plot of g as a function of B, for the case of a *global field*, verifying this relation. This result suggests that g should drop to zero as $B \to 0$. The partial drops observed in Fig. 3.6 seem to be due to finite size effects for $B \to 0$. A detailed investigation of such finite size effects is reported in Fig. 3.9 for the case of the *global field*. It is seen that, for very small values of B, the values of g decrease as the system size N increases. However, for values of $B \gtrsim 10^{-2}$, the variation of the size of the system does not affect g significantly.

Figure 3.10 displays the dependence of g on the size of the system N when $B \to 0$ for the three interaction fields being considered. For each size N, a value of g associated with each field was calculated by averaging over the plateau values shown in Fig. 3.9 in the interval $B \in [10^{-5}, 10^{-3}]$. The mean values of g obtained when $B = 0$ are also shown for reference. The order parameter g decreases for the three fields as the size of the system increases; in the limit $N \to \infty$ the values of g tend to zero and the system becomes homogeneous in the three cases. For small values of B, the system subject to the *local field* exhibits the greatest sensitivity to an increase of the system size, while the effect of the constant *external field* is less dependent on system size. The ordering effect of the interaction with a field as $B \to 0$ becomes more

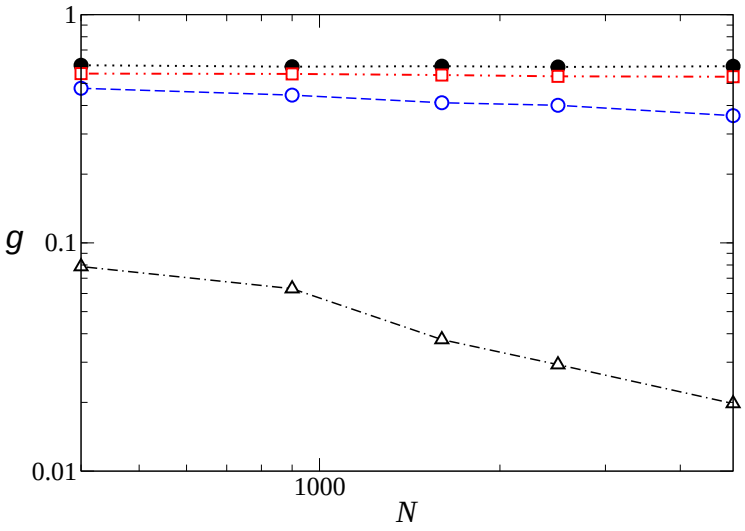

Figure 3.10: Mean value of the order parameter g as a function of the system size N without field ($B = 0$, solid circles), and with an *external* (squares), *global* (circles) and *local field* (triangles). Parameter value $q = 30$.

evident for a local (nonuniform) field. But, in any case, the system is driven to full order for $B \to 0$ in the limit of infinite size by any of the interacting fields considered here.

Chapter 4

Global field and the filtering of local interactions: Indirect mass media influence

In this chapter we analyze a model of global information feedback where the global mass media acts as a moderator or filter of the local influence of neighbors, as proposed by Shibanai et al. [43]. In the original Axelrod's model one feature with different traits for two neighboring agents is chosen, and the trait of the active agent is changed to that of the neighbor. This is modified in the model of indirect global mass media influence analyzed here, taking into account the agreement of the chosen trait of the neighbor and that of the global mass media or *the plurality* of the population. If the trait of the neighbor is concordant with the dominant one, that is, the same as that of the global mass media message M, the feature of the active agent will be changed to that of the neighbor. But if the feature of the neighbor is different from that of the global mass media message M, then, with probability R the active agent will not change. Thus, this model assumes that agents are more likely to adopt a trait from those neighbors that are concordant with the plurality.

We use the definition of a uniform global mass media as in Section 1.1, $M = (\mu_{i1}, \mu_{i2}, \ldots, \mu_{iF})$. The dynamical evolution of the filter model can be described in terms of the following iterative steps:

(1) Select at random an agent i on the lattice (active agent).

(2) Select at random one agent j among the four neighbors of i.

(3) Calculate the overlap $l(i,j)$. If $0 < l(i,j) < F$, sites i and j interact with probability $p_{ij} = l(i,j)/F$. In case of interaction, choose g randomly such that $C_{i]^g} \neq C_j^g$. If $C_j^g = \mu_g$, then set $C_i^g = C_j^g$; otherwise with probability R the state of agent i does not change and with probability $1 - R$ set $C_i^g = C_j^g$

(4) Update the global mass media vector M if required. Resume at (1).

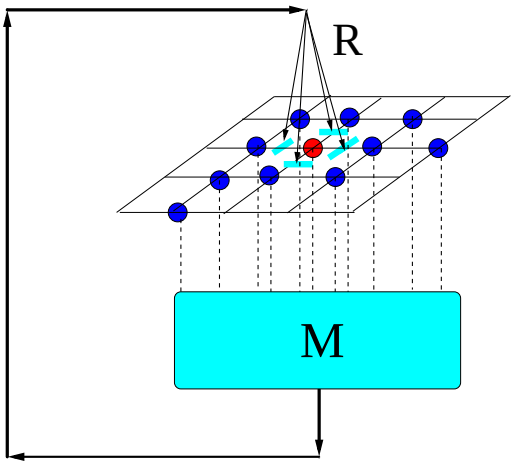

Figure 4.1: Diagram representing the filter model.

Figure 4.1 shows a diagram of the filter model. The parameter R describes the intensity of the filtering effect of the global mass media on the local interactions. The case $R = 0$ corresponds to the original Axelrod's model, while $R = 1$ implies that cultural interaction only causes a change if the chosen trait of the neighbor was equal to that of the global mass media. The overall probability of interaction between an active agent i and a chosen neighbor j is $p_{ij}(1 - R)$ if the chosen trait of j is different from that corresponding to M, and p_{ij} if the chosen trait is equal to that corresponding to M.

Figure 4.2 shows the average fraction of cultural domains g as a function of time in the global mass media filter model, for two values of q with $F = 5$, and for different values of the filtering probability R. In Fig. 4.2 (left), when $q < q_c$ the system reaches a homogeneous state for $R = 0$ and also for small values of R. However, when the probability R increases, the filtering influence of the global mass media can induce cultural diversity. Our results for $q < q_c$ support the results obtained by Shibanai et al. [43] about the ability of the filtering process to induce cultural diversity in the same fashion as the model with direct global mass media influence. But comparison with Fig. 4.3, where we plot the average fraction of cultural domains g as a function of time under the direct action of global mass media, for $q < q_c$ with $F = 5$, and for different values of the probability B, shows that direct interaction with global mass media is more efficient in promoting cultural diversity than the filtering mechanism of agreement with the global plurality.

The analysis of reference [43] was restricted to a single value of $q < q_c$. We have also explored values of $q > q_c$, where the system would be in a heterogeneous cultural state in absence of any filtering ($R = 0$). For these values

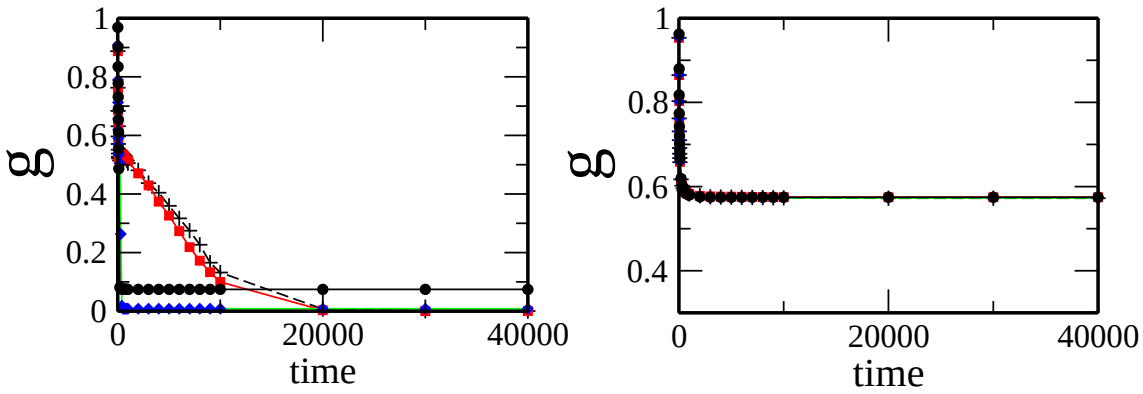

Figure 4.2: Time evolution of the average fraction of cultural domains g in the filter model for different values of the probability R, with fixed $F = 5$. Time is measured in number of events per site. System size $N = 50 \times 50$. Left: $q = 10$; $R = 0$ (crosses); $R = 0.0005$ (squares); $R = 0.15$ (diamonds); $R = 0.6$ (circles). Right: $q = 30$; $R = 0$ (crosses); $R = 0.0005$ (squares); $R = 0.005$ (circles); $R = 0.1$ (diamonds).

of q we find (Fig. 4.2, right) that the filtering mechanism has no appreciable effects for small R, in contrast with the case of direct global mass media influence where for small values of the probability of interaction B with the media message, the number of cultural groups is reduced as a consequence of this interaction.

A systematic analysis of the filtering effect for different values of q is summarized in Figure 4.4 which shows the asymptotic value for long times of the average fraction of cultural domains g as a function of q, with $F = 5$, for different values of the filtering probability R. When no filtering acts on the system ($R = 0$) the behavior is that of the original Axelrod's model and also coincides with the direct mass media models for $B = 0$.

The effects of the filtering process in the culturally homogeneous region, i.e., for parameter values $q < q_c$, is similar to that of a direct influence of endogenous mass media. When the probability R is increased, the threshold value of q decreases. There is a value $q_c(R)$ below which the system still reaches a homogeneous cultural state under the influence of the filter. An increase in R for parameters $q < q_c(R)$ leads to cultural diversity. Thus, both mechanisms of feedback information, either direct or indirect, promote multiculturality in the region of parameters where globalization prevails in the absence of any feedback. The similar behavior found for the all types of mass media influences considered here suggests that the phenomenon of mass media-induced diversity should be robust in this region of parameters, regardless of the type of feedback mechanism at work.

However, in the region of parameters $q > q_c$ where multiculturality oc-

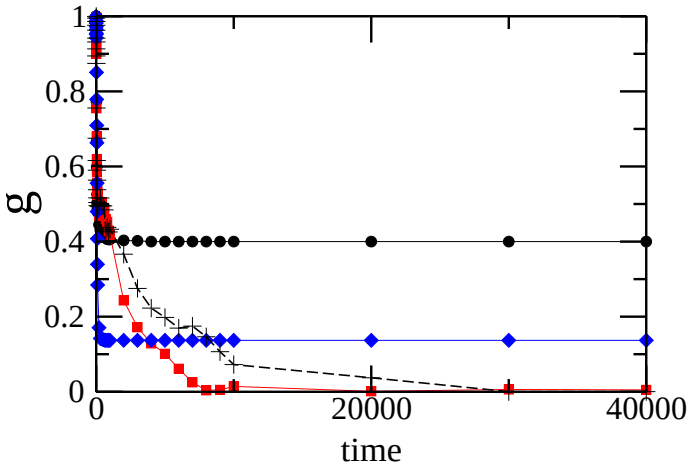

Figure 4.3: Evolution of g in a system subject to a global mass media message for different values of the probability B, with fixed $F = 5$. Time is measured in number of events per site. System size $N = 50 \times 50$, $q = 10$; $B = 0$ (crosses); $B = 0.0005$ (squares); $B = 0.15$ (diamonds); $B = 0.6$ (circles).

curs for $R = 0$ or $B = 0$, the behavior of the filter model differs from those of the direct mass media influence. The filtering mechanism has little effect for values of the probability $R < 1$. As $R \to 1$ there is a small decrease in the number of cultural groups formed in the system. But at $R = 1$ a discontinuity appears: the fraction of cultural groups g jumps from a value close to the one for $R = 0$ to a value close to $g = 1$ corresponding to maximum multiculturality (number of cultural groups equal to the number of agents in the system). The case $R = 1$ corresponds to an extreme restriction on the dynamics, when no adoption of cultural features from neighbors is allowed unless the state of the neighbor coincides with the one of the global mass media. Since we are considering random initial conditions, when q is large enough, the probability that the features of any agent coincide with those of the global mass media message M is quite small, making the convergence to globalization, i.e., a common state with the media, very unlikely. As a consequence, the random multicultural state subsists in the system and manifests itself as a maximum value of g. The small probability of interaction with the global mass media for large values of q when $R = 1$ is also reflected in the very long convergence time needed to reach the final multicultural state as compared with the convergence time for $R < 1$.

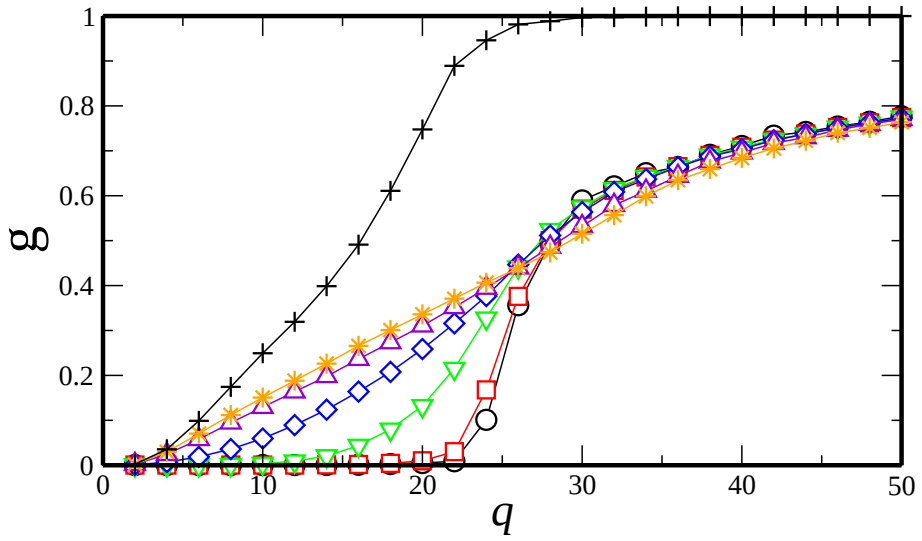

Figure 4.4: Average fraction of cultural domains g as a function of q, for different values of the probability R for the filter model. $R = 0$ (circles); $R = 0.01$ (squares); $R = 0.1$ (triangles down); $R = 0.5$ (diamonds); $R = 0.9$ (triangles up); $R = 0.99$ (stars); $R = 1.0$ (plus signs)

Chapter 5

Summary and conclusions

We have analyzed a nonequilibrium lattice model of locally interacting elements and subject to additional interacting fields. The state variables are described by vectors whose components take discrete values. We have considered the cases of a constant *external field*, a *global field*, and a *local field*. The interaction dynamics, based on the similarity or overlap between vector states, produces several nontrivial effects in the collective behavior of this system.

We have first studied (Chapter 3) the effects of these different types of field in the context of Axelrod's interaction rules in which the fields acts as an additional neighbor with some probability to interact. With these defined rules, mass media have a direct influence on each agent. We find two main effects that contradict intuition based on the effect of interacting fields in equilibrium systems where the dynamics minimizes a potential function. First, we find that an interacting field might disorder the system: For parameter values for which the system orders due to the local interaction among the elements, there is a threshold value B_c of the probability of interaction with a field. For $B > B_c$ the system becomes disordered. This happens because there is a competition between the consequences of the similarity rule applied to the local interactions among elements, and applied to the interaction with the field. This leads to the formation of domains and to a disordered system. A second effect is that, for parameter values for which the dynamics based on the local interaction among the elements leads to a frozen disordered configuration, very weak interacting fields are able to order the system. However, increasing the strength of interaction with the field produces growing disorder in the system. The limit $B \to 0$ is discontinuous and the ordering effect for $B << 1$ occurs because the interaction with the field acts as a perturbation on the non stable disordered configurations with frozen dynamics appearing for $B = 0$. In this regard, the field behaves similarly to a random fluctuation acting on the system, which always induces order for small values of the noise rate [49].

These results are summarized in Fig. 5.1 which shows, for different val-

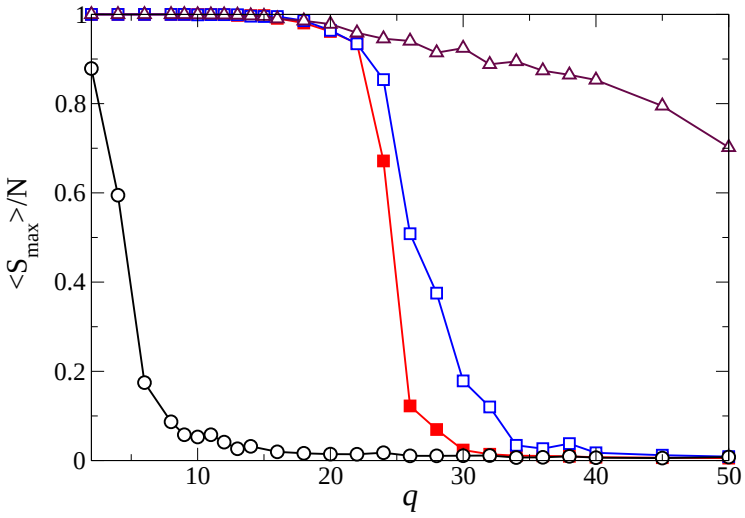

Figure 5.1: Influence of the interacting field on the nonequilibrium order-disorder transition as described by the order parameter $\langle S_{max}\rangle/N$. Results are shown for $B = 0$ (solid squares), a *global* ($B = 10^{-5}$ (empty squares), $B = 0.3$ (circles)) and a *local* ($B = 10^{-5}$ (triangles)) *field*. Parameter value $F = 3$.

ues of B, the behavior of the order parameter $\langle S_{max}\rangle/N$ previously considered in Fig. 1.2. For small values of B, the interaction with a field can enhance order in the system: for $q < q_c$ interaction with a field preserves homogeneity, while for $q > q_c$ it causes a drop in the degree of disorder in the system. In an effective way the nonequilibrium order-disorder transition is shifted to larger values of q when B is non-zero but very small. For larger values of B the transition shifts to smaller values of q and the system is always disordered in the limiting case $B \to 1$. This limiting behavior is useful to understand the differences with ordinary dynamics leading to thermal equilibrium in which a strong field would order the system. In our nonequilibrium case, the similarity rule of the dynamics excludes the interaction of the field with elements with zero overlap with the field. Since the local interaction among the elements is negligible in this limit, there is no mechanism left to change situations of zero overlap and the system remains disordered. We have calculated, for the three types of field considered, the corresponding boundary in the space of parameters (B, q) that separates the ordered phase from the disordered phase (see Fig. 3.5). In the case of a constant *external field*, the ordered state in this phase diagram always converges to the state prescribed by the constant field vector. The nonuniform *local field* has a greater ordering effect than the uniform (*global* and constant *external*) fields in the regime $q > q_c$. The range of values of B for which the system is ordered for $q < q_c$ is also larger for the nonuniform *local field*.

In spite of the differences mentioned between uniform and nonuniform

fields, it is remarkable that the collective behavior of the system displays analogous phenomenology for the three types of fields considered, although they have different nature. At the local level, they act in the same manner, as a "fifth" effective neighbor whose specific source becomes irrelevant. In particular, both uniform fields, the *global* coupling and the *external field*, produce very similar behavior of the system. Recently, it has been found that, under some circumstances, a network of locally coupled dynamical elements subject to either global interactions or to a uniform external drive exhibits the same collective behavior [61, 62]. The results from the present nonequilibrium lattice model suggest that collective behaviors emerging in autonomous and in driven spatiotemporal systems can be equivalent in a more general context.

In the context of Axelrod's model for the dissemination of culture [42] the interacting fields that we have considered can be interpreted as different kinds of mass media influences acting on a social system. In this context, our results suggest that both, an externally controlled mass media or mass media that reflect the predominant cultural trends of the environment, have similar collective effects on a social system. We found the surprising result that, when the probability of interacting with the mass media is sufficiently large, mass media actually contribute to cultural diversity in a social system, independently of the nature of the media. Mass media is only efficient in producing cultural homogeneity in conditions of weak broadcast of a message, so that local interactions among individuals can be still effective in constructing some cultural overlap with the mass media message. Local mass media appear to be more effective in promoting uniformity in comparison to global, uniform broadcasts.

In Chapter 4 we have considered a model [43] of inderect mass media influence. The dynamical considered acts as filtering process for the agent-field interaction. In the culturally homogeneous region, i.e., for $q < q_c$, the effect of this indirect influence is similar to that caused by a direct influence of mass media. For small values of the filtering probability R the system reaches a culturally homogeneous state. For values of R greater than a threshold value the system converges to a state of cultural diversity. Thus, both mechanisms of feedback information, either direct or indirect, promote multiculturality in a region of parameters where it would not be present in the absence of any feedback. In the region of parameters $q > q_c$ where multiculturality occurs for either $B = 0$ or $R = 0$, the filtering mechanism has, for values of the probability $R < 1$, a very weak effect in comparison to the one caused by a direct mass media influences: there is only a small decrease in the number of cultural groups formed. However, when the extreme restriction $R = 1$ is imposed, the number of cultural groups jumps discontinuously to a value corresponding to maximum multiculturality.

Generally speaking, our analysis unveils the delicate compromise between

direct agent-agent interactions and feedback processes. Mass media reflects local or global cultural trends created by local agent-agent interaction, but mass media information is processed by agent interactions, while the agent-mass media interaction is conditioned by the overlap of the cultural features of the agent and the mass media message. We have analyzed the effect of different forms of mass media for the full range of the parameter q that measure an initial cultural diversity. Our results indicate qualitatively different effects when globalization ($q < q_c$) or polarization ($q > q_c$) would prevail when no mass media feedback is taken in account. We find that, when the probability of interacting with the mass media is sufficiently large, mass media actually contribute to cultural diversity in a social system, independently of the nature of the media. But direct mass media influences are found to be efficient in promoting cultural homogeneity in conditions of weak broadcast of a message, so that local interactions among individuals can be still effective in constructing some cultural overlap with the mass media message. Strong media messages do not lead to cultural homogenization because agent-agent interaction becomes inefficient. These results identify the power of being subtle in mass media massages. In addition, direct local mass media appear to be more effective in promoting uniformity in comparison to direct global broadcasts, which identifies the importance of local media (feedback at regional levels) in the cultural globalization path.

Finally, we note that the case $B = 1$ in the model of direct global mass media influence is less restrictive than the condition $R = 1$ in the filter model. Although local agent-agent interactions produce negligible effects in both cases, in the model of direct influence, an agent can still interact with the global mass media when there is some cultural overlap between the agent and the mass media message.

In summary, we find that ours results substantiate previous findings by Shibanai et al. showing that cultural diversity is favored by increasing the strength of the mass media influence. This effect occurs independently of the mechanisms of action of the mass media message. However, through an analysis of the full range of parameters measuring cultural diversity, we establish that the enhancement of cultural diversity produced by interaction with mass media only occurs for strong enough mass media messages. A main different result is that weak mass media messages, in combination with agent-agent interaction, are efficient in producing cultural homogeneity. Moreover, the homogenizing effect of weak mass media messages are more efficient for local field than for global or external field.

Future extensions of this work can considere the competition between noise and different fields, as well as the analysis in different networks, such as, scale-free [63], small world [64] or a co-evolution networks [9, 56].

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