Interacting networks as models of cultural change

Federico Cecconi Daniele Caligiore
Gianluca Baldassarre Domenico Parisi

Institute of Cognitive Sciences and Tecnologies
National Research Council
44 Via San Martino della Battaglia, 00185 Rome
federico.cecconi, daniele.caligiore, gianluca.baldassarre, domenico.parisi@istc.cnr.it

1. Introduction

Every individual has behaviours, beliefs, and values which are different from the behaviours, beliefs, and values of other individuals. However, if individuals interact with each other there will be a tendency for their behaviours, beliefs, and values to become more similar because of imitation, teaching, and social learning. A group of individuals interacting with each other will tend to have the same behaviours, beliefs, and values, which will constitute their shared culture.

Change in the behaviours, beliefs, and values of individuals due to influences from other individuals, i.e., cultural dynamics, is increasingly investigated using formal models, following a consolidated tradition of social network analysis (Wasserman and Faust, 1994) and more recent attempts at using mathematical/physical modeling tools and computer simulations to study social and cultural phenomena (Bourgine and Nadal, 2006; Chakrabarti, Chakrabarti, and Chatterjee, 2006). Using cellular automata Axelrod (1997) has studied how the culture of a collection of individuals changes because of the interactions of each individual with other individuals living nearby in a bi-dimensional space. (See also Friedkin and Johnsen, 1990; Kennedy, 1998; Cecconi, Natale, and Parisi, 2003.) In other work (Castellano, Loreto, Barrat, Cecconi, and Parisi, 2005; Lima and Stauffer, 2006; Guo and Szeto, 2007), groups of individuals are represented as networks of nodes and the interactions among the individuals depend on network topology rather than on spatial proximity. In both cases, individuals start with randomly assigned and therefore individually different behaviours, beliefs, and values, and these formally represented behaviours, beliefs, and values change because of inter-individual interactions. One important difference between interactions based on spatial proximity and interactions not based on spatial proximity is that the first type of interactions tend to result in separate, internally homogeneous cultures and in the appearance of fixed cultural boundaries, while the second type of interactions tend to generate a single, global culture. This is an interesting result given that advances in transportation of people, commodities, and information tend to create a network of possible interactions which is independent of spatial distance and therefore favours the emergence of a single, homogeneous, global culture.

Cultural dynamics can also take place when two previously separate groups of individuals start to influence each other because of new opportunities of inter-group interactions. Imagine two groups of individuals which interact within their own group but do not interact with the individuals of the other group (Figure 1a). The two groups will have an internally homogeneous culture but their two cultures will be different. At some point, however, the opportunity arises for inter-group interactions. One or more individuals of one group interact with individuals of the other group (Figure 1b). This can lead to changes in the cultures of the two groups, with results that will depend on various factors such as the size of the two groups, the number of intra-group and inter-group interactions, and whether or not inter-group interactions replace intra-group interactions.

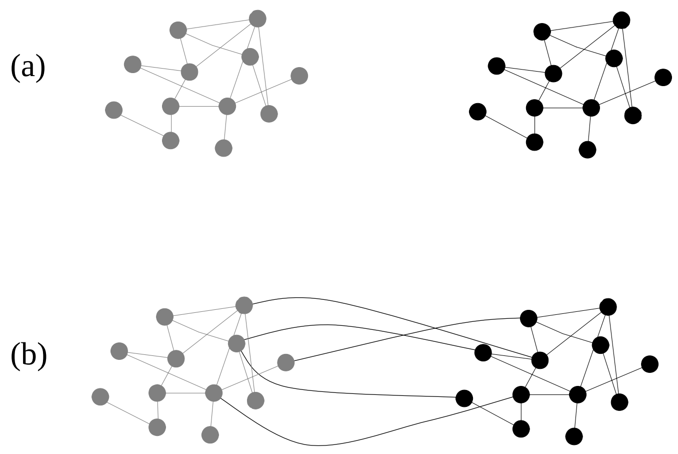

Figure 1. (a) Two separate networks representing two groups of non-interacting individuals. (b) At some point external links are added that connect one network with the other network. These external links represent opportunities for inter-group interactions.

In this paper we will use formal models and computer simulations to explore some consequences of adding inter-group interactions for the cultures of two previously separated groups. Individuals are represented as nodes and inter-individual interactions as links between nodes. Therefore a group of individuals that interact with each other is represented as a network of nodes. The behaviours, beliefs, and values of each individual are represented as a string of bits associated with each node. The starting point of all our simulations is two separate groups of individuals with different cultures, i.e., two networks of nodes with two different strings of bit. Then we add one or more links between the two networks (external links) that simulate interactions between one or more individuals of one group with individuals of the other group. If two nodes that have a different string of bit associated to them are linked together, the two strings of bits of the two nodes will change, and we decide what is the rule that controls that change. What we want to explore is the cultural dynamics that takes place as a function of a number of variables that we manipulate in different simulations. The first variable is the number of nodes in the two networks (size of cultural groups). In some simulations the two networks have the same number of nodes but in other simulations one network is larger than the other one. The second variable is the internal connectivity of the two networks. We manipulate the strength of their internal connectivity (number of internal links) by varying the probability that one node is linked to another node of the same network. In some simulations both networks have the same internal connectivity but in other simulations one network can have a higher internal connectivity than the other network. The third variable is the manner in which we add external (inter-network) links. In some simulations external links are simply added to the two networks but the two networks maintain their internal links. In other simulations external links replace internal links, either in both networks or in only one of the two networks.

2. Detailed description of the two networks and of the variables manipulated in the simulations

Network size. In some simulations the two networks have the same size, i.e., 250 nodes each, and in other simulations one network has 350 nodes and the other network has 150 nodes.

Internal connectivity. In some simulations the internal connectivity of the two networks is the same but in other simulations is different. In both cases we manipulate internal connectivity by varying the probability that one node is linked to another node of the same network. The probabilities can be 20%, 50%, or 80%.

String of bits. All the nodes of the same network have the same string of 5 bits associated to them, but the two networks have different bits of strings. The two strings of bits are randomly generated.

External links. We add external links in three different manners:

Added Wiring (AW): we add external links without changing the internal links of the two networks;

Asymmetrical Rewiring (AR): each added external link replaces one internal link in one of the two networks, always the same;

Symmetrical Rewiring (SR): each added external link replaces one internal link in both networks.

AW does not weaken the internal connectivity of the two networks. AR weakens the internal connectivity of one network and leaves intact the internal connectivity of the other network. SR weakens the internal connectivity of both networks.

Rule of cultural dynamics. At the beginning of the simulation, when the two networks are separate and they are internally completely homogeneous, there is no cultural dynamics since all the nodes of each network have the same string of bits associated to them. However, when external links are added the string of bits of one node can change because the node can interact with nodes that have a different string of bits. The rule which we apply to implement this change is the Frequency Bias Rule (Boyd and Richerson, 1985). In each cycle and for all the nodes of the two networks, for each bit of the string of bits associated with the node, we assign to the bit the value of the corresponding bit possessed by the majority of nodes linked to the node. In case of parity, the value is randomly chosen.

Simulations run in cycles. In each cycle we update the string of bits associated with each node and the simulation ends when there are no more changes. Each simulation is repeated 100 times for each number of added external links. For each simulation we determine the percentage of runs in which we observe the emergence of a single homogeneous culture (same string of bits for all the nodes of both networks).

3. Results

Figure 2 shows the probability of emergence of a single, homogeneous culture in two groups of individuals as a function of the percentage of total links (internal links plus external links) that are external links. The Figure contains two sets of three curves. The three curves on the right refer to a method of adding external links that leaves internal links intact (Added Wiring, AW), while the three curves on the left refer to a method of adding external links where for each added external link an internal link is cancelled always in the same network (Asymmetrical Rewiring, AR). The two groups of individuals have the same size (250) and the same internal connectivity (probability that two nodes are internally linked) but the Figure has separate curves for three different internal connectivities: 20%, 50%, and 80%.

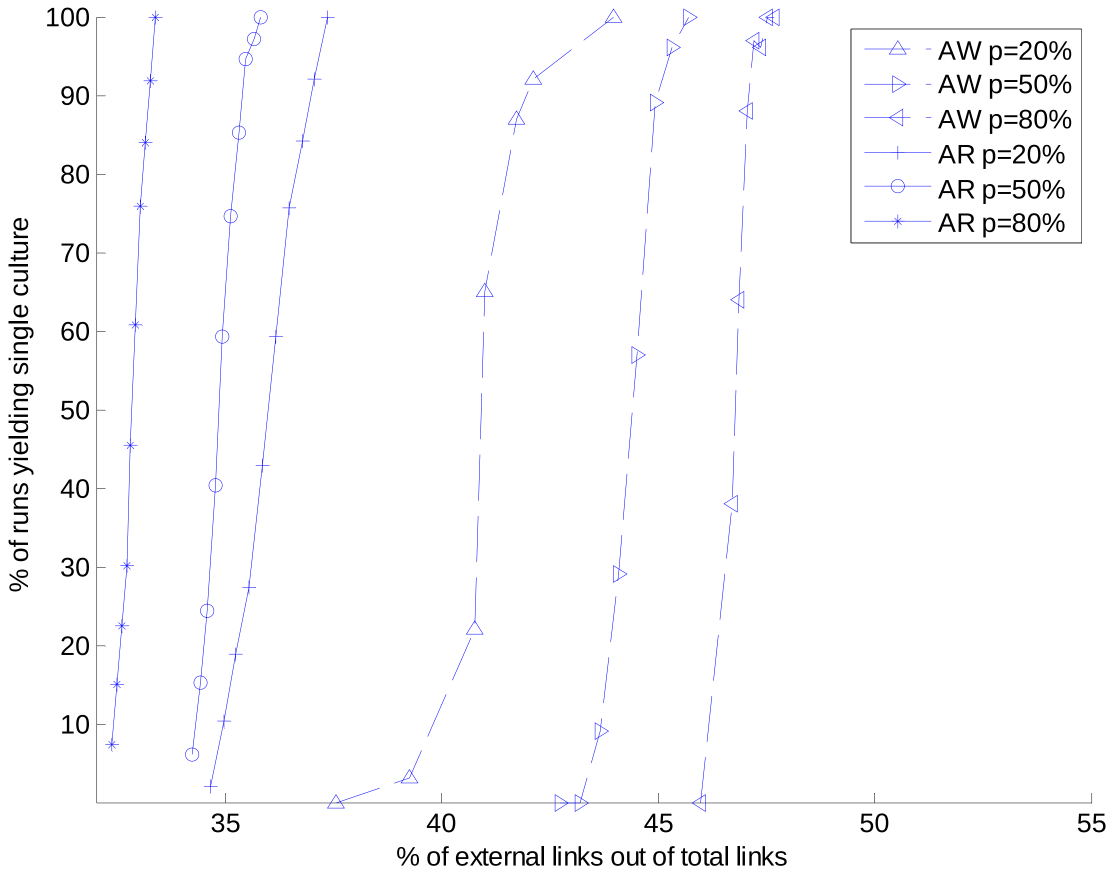

Figure 2. Probability of emergence of a single culture as a function of percentage of total links that are external links. The two groups of individuals have the same size and the same internal connectivity. The three curves on the right are the result of Added Wiring (AW: external links do not replace internal links),,while the three curves on the left are the result of Asymmetrical Rewiring (AR: external links replace internal links in one of the two networks, always the same). Groups can have internal connectivity of 20%, 50%, or 80%.

Figure 2 demonstrates that a single, unified culture in two previously culturally distinct groups emerges with increasing probability as the number of opportunities of interaction between individuals belonging to the two groups increases. However, a single culture emerges even if external links (interactions) are just one third of total links. Another result shown by Figure 2 is that if external links replace internal links in only one of the two networks the emergence of a single culture is facilitated in comparison to adding external links without eliminating internal links. A third result is that more internal links (greater internal connectivity) are an obstacle to the emergence of a single culture if external links are added to internal links. On the contrary, internal links facilitate the emergence of a single culture if external links replace internal links.

Figure 3 shows similar results as those of Figure 2 but using Symmetric Rewiring (SR): adding an external link is now accompanied by the elimination of an internal link in one of the two networks which is each time randomly chosen. Therefore, the internal connectivity of both networks is weakened. The results for Asymmetric Rewiring already presented in Figure 2 are also shown for comparison.

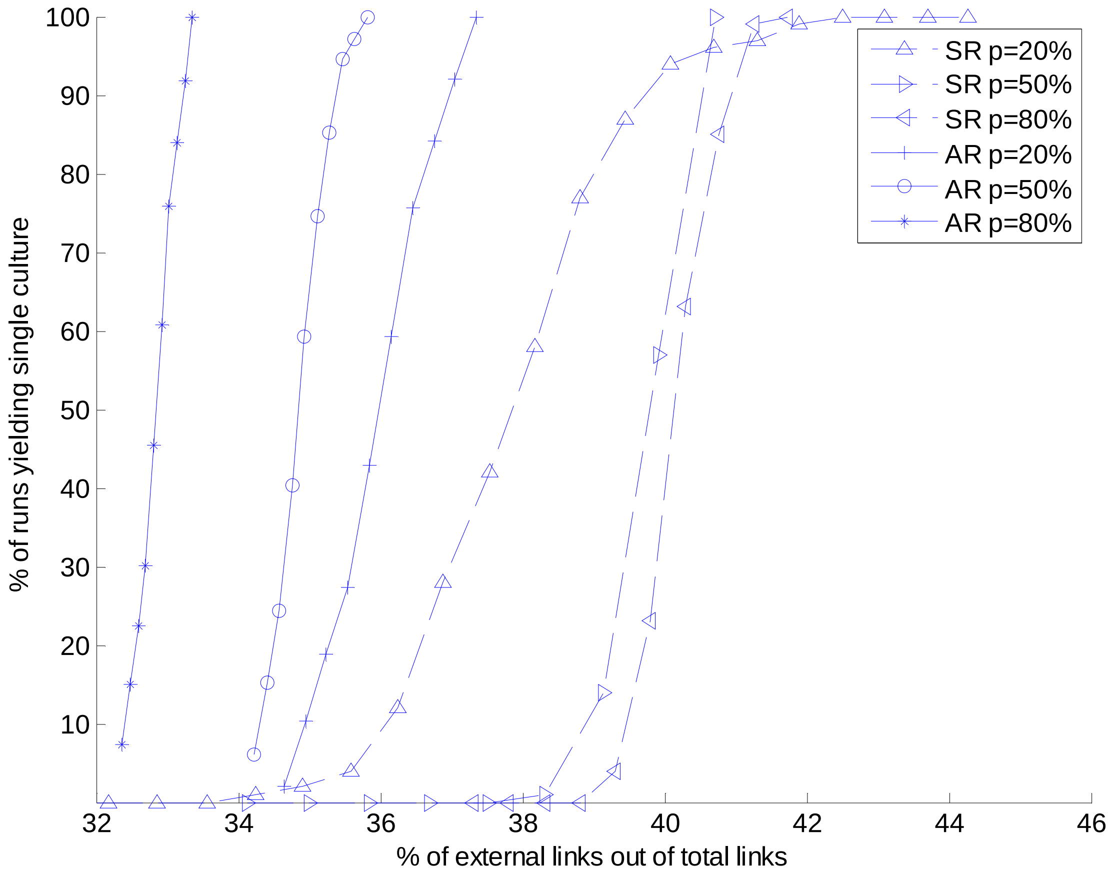

Figure 3. Probability of emergence of a single culture as a function of percentage of total links that are external links, but with Symmetrical Rewiring (SW: external links replace internal links in both networks). The results for Asymmetric Rewiring already presented in Figure 2 are also shown for comparison.

Figure 3 shows that with Symmetric Rewiring the probability of the emergence of a single culture is intermediate between the probability with Added Rewiring and the probability with Asymmetric Rewiring (cf. Figure 2). Furthermore, with Symmetric Rewiring increasing internal connectivity is an obstacle to the emergence of a single culture, as with Added Wiring (cf. Figure 2).

All the results presented so far refer to pairs of networks that have the same size and the same internal connectivity. Figure 4 shows what happens if the two networks have different sizes (350 vs. 150) and the same internal connectivity (80%), or they have the same size (250 and 250) and different internal connectivities (20% vs. 80%).

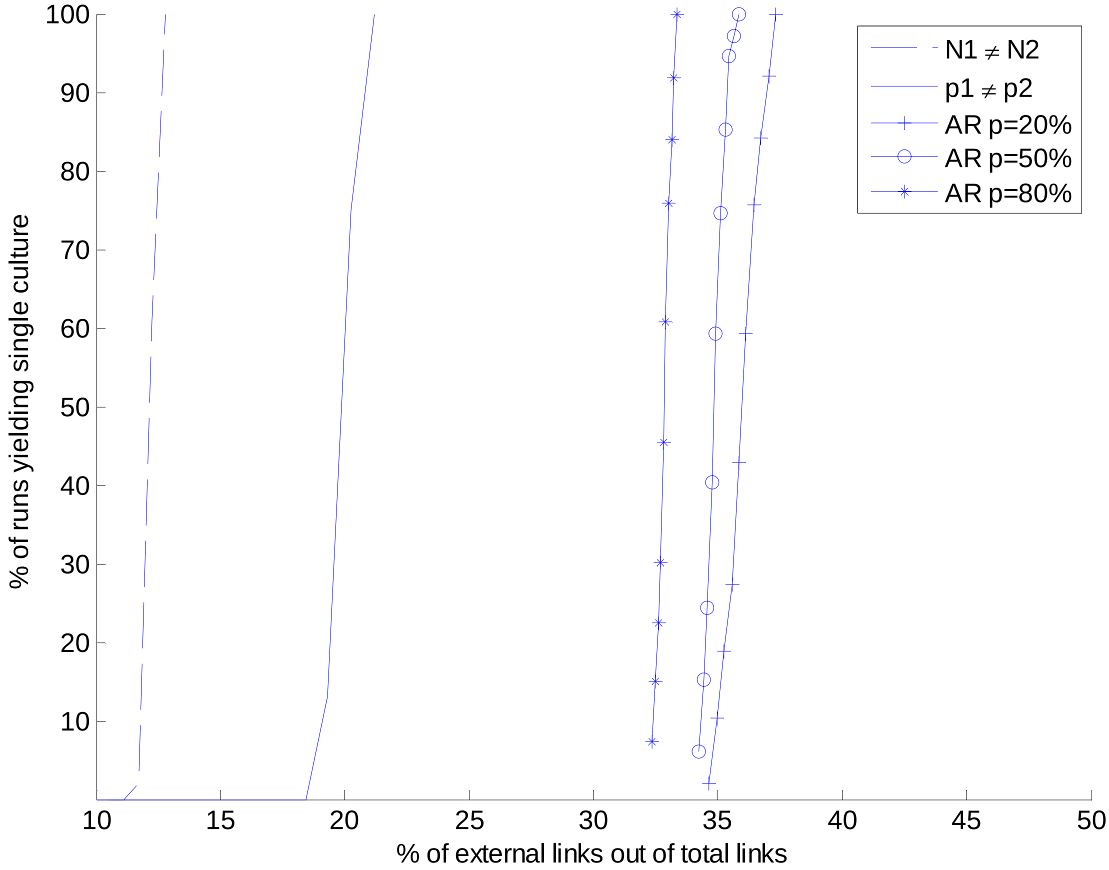

Figure 4. Probability of emergence of a single culture as a function of percentage of total links that are external links in pairs of networks that either have different sizes (350 vs. 150 nodes) and the same internal connectivity (80%) or have different internal connectivities (20% vs. 80%) and the same size (250 nodes). External links are added using Added Wiring. The results for Asymmetric Rewiring already presented in Figure 2 are also shown for comparison.

Figure 4 shows that differences in size between the two networks make the emergence of a single culture highly probable even with very small numbers of external links. This is also true, although to a more limited extent, for differences of internal connectivity between the two networks.

A final result concerns what is the single, homogeneous culture that emerges in the different simulations. There are two possibilities: either the emerging single culture is a third culture which is different from both the initial culture of one group and the initial culture of the other group, or the single culture is the initial culture of one of the two groups, which has simply replaced the culture of the other group. The results are that, for pairs of networks with the same size and the same internal connectivity, the symmetrical methods of adding external links, i.e., Added Wiring and Symmetrical Rewiring, result in the emergence of a new culture which is different from the initial cultures of both networks. However, Asymmetrical Rewiring causes the culture of the network whose internal connectivity has been weakened to be replaced by the culture of the other network. On the other hand, if the two networks are asymmetrical from the beginning, i.e., one network is larger or has more internal connectivity than the other network, the culture of the network which is larger or has more internal connectivity replaces the culture of the other network even if external links are added without eliminating internal links (Added Wiring).

4. Discussion and conclusions

Which factors accelerate or slow down the emergence of a single culture in two previously separated groups of individuals when there are new opportunities of inter-group interactions? A single, homogeneous culture emerges more probably, i.e., with the addition of fewer possibilities of inter-group interactions, if external links replace internal links in one of the two groups. The individuals of one group are convinced not to interact with other individuals of the same group in order to interact with the individuals of the other group, and this happens asymmetrically only in one of the two groups. Furthermore, in these circumstances, the single culture which emerges is the culture of the other group which simply replaces the initial culture of the internally weakened group.

More possibilities of inter-group interactions (a greater number of external links) are needed for the emergence of a single culture if inter-group interactions replace intra-group interactions in both groups, and even more if inter-group interactions are added to intra-group interactions but the internal connectivity of the two groups is not weakened. In these circumstances, the single culture which emerges is a new culture which is different from the originary cultures of both groups.

It is interesting to comment on the role of internal connectivity in cultural dynamics. If opportunities of inter-group interactions replace opportunities of intra-group interactions in only one group (Asymmetric Rewiring), a greater internal connectivity of the group which is internally weakened accelerates rather than slowing down the replacement of the culture of the group by the culture of the other group. In fact, the culture of the other group appears to more easily penetrate in the weakened group if the weakened group is initially more internal connected, i.e., has more opportunities of intra-group interactions. In contrast, if there is no asymmetry between the two groups since opportunities of inter-group interactions are simply added to opportunities of intra-group interaction or replace them in both groups, a greater internal connectivity slows down cultural homogeneization.

Other factors that play an important role in the sort of inter-group cultural dynamics studied in our simulations are the initial asymmetries between interacting groups. If one group is larger than another group, this results in an acceleration of cultural homogenization, and the same is true if one group has more internal connectivity of the other group. In both cases there is cultural colonization, and the emerging single culture is the culture of the group which is larger or has more internal connectivity.

The results of our simulations can be interpreted as reflecting some of the current phenomena of cultural globalization. Advances in transport technologies for people, commodities, and information increase the possibilities of interaction among individuals who belong to previously separate cultural communities, and this tends to result in the emergence of a global culture. However, if we are specifically interested in today’s cultural globalization we should consider other rules of cultural dynamics beyond the Frequency Bias Rule. The Frequency Bias Rule assumes that individuals tend to change their behaviours, beliefs, and values by incorporating the behaviours, beliefs, and values of the majority of people with which they interact in one way or another. However, there are other mechanisms of inter-individual influence. For example, one individual can be imitate another individual because the first individual perceives the behaviours, beliefs, and values of the second individual as leading, directly or indirectly, to a better life (cf. Boyd and Richerson’s (1985) Direct Bias and Indirect Bias.) These factors tend to favour Western culture in that this culture is perceived as producing more wealth. Our simulations can be extended to incorporate these additional rules of cultural dynamics, which may turn out to be more important than the variables which have been manipulated in our simulations, in particular differences in group size. If one group is smaller than another group, say America vs. China, but the first group has behaviours, beliefs, and values which lead to more wealth, and if we apply not only Boyd and Richerson's Frequency Bias but also their Direct or Indirect Bias, increasing possibilities of interaction between individuals belonging to the two groups may lead to the extension of the culture of the smaller group to the larger group. This may explain why cultural globalization appears to be largely cultural Americanization.

Another interesting variable that could be studied in extensions of our simulations is network topology. Our networks are random networks but it is well known that network topology (e.g., scale free, small world topologies) is an important variable in many applications of networks (Barabasi and Albert, 1999). This has been demonstrated in applications of networks to cultural dynamics when a single network is considered (e.g., Castellano, Loreto, Barrat, Cecconi, and Parisi, 2005) and should also be considered when two networks interact with each other. The phenomena of cultural globalization that our simulations may contribute to better understand are likely to be sensitive to specific structures of intra-group interactions which are formally captured by network topology.

References

Axelrod, R. 1997. The dissemination of culture: a model with local convergence and global polarization. Journal of Conflict Resolution, 41:203-226.

Barabasi, A.L., Albert, R. Emergence of scaling in random networks. Science, 1999, 286, 509-512.

Bourgine, P., Nadal, J-P. Cognitive economics: an interdisciplinary approach. New York, Springer, 2006.

Boyd, R. and Richerson, P. J. 1985. Culture and the Evolutionary Process. Chicago: Chicago University Press.

Castellano, C., Loreto, V., Barrat, A., Cecconi, F., Parisi, D. Comparison of voter and Glauber ordering dynamics in networks. Physical Review E, 71, 2005, 66107-1:8.

Chakrabarti, B. K., Chakrabarti, S., Chatterjee, A. (eds.), Econophysics and Sociophysics: Trends and Perspectives. New York, Wiley, 2006.

Friedkin, N.E., Johnsen, E.C. 1990. Social influence and opinion. Journal of Mathematical Sociology, 25:193-205.

Guo, Z.Z., Szeto, K.Y. Survivor statistics and damage spreading on social network with power law degree distributions. Physica A, 2007, 374, 471-477.

Lima, F.W.S., Stauffer, D. Ising model simulation in directed lattices and networks. Physica A, 2006, 359, 423.429.

Wasserman, S., Faust, K. Social network analysis. Methods and Applications. Cambridge, Cambridge University Press, 1994.