Can a few fanatics influence the opinion of a large segment of a society?

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Can a few fanatics influence the opinion of a large segment of a society?[1]

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Models that provide insight into how extreme opinions about any social phenomenon may spread in a society or at the global scale are of great current interest. A realistic model must account for the fact that globalization, internet, and other means of mass communications have given rise to scale-free (SF) networks of interactions between people. We carry out extensive simulations of a new model which takes into account the SF nature of the interactions network, and provides some key insights into the phenomenon. The insights include, (1) the existence of a fundamental difference between a hierarchical network whereby people are infuenced by those that are higher in the hierarchy but not by those below them, and a symmetrical network where person-on-person influence works mutually, and (2) the key result that a few "fanatics" can influence a large fraction of the population either temporarily (in the hierarchical interaction networks) or permanently (in symmetrical interaction networks). Even if the fanatics themselves disappear, the population may still remain susceptible to the ideologies or opinion originally advocated by them. The model is, however, general and applicable to any phenomenon for which there is a degree of enthusiasm, or susceptibility to, in the population.

I INTRODUCTION

Given the current political climate around the world, and the rise of extreme ideologies in many parts of the globe, models that can provide insight into how such ideologies and opinions spread in a society are clearly of great interest. To develop such models, one should keep in mind two well-known facts:

(1) Globalization, the internet, and other modern means of long-distance communications (for example, fax and mobile phones) have given rise to scale-free (SF) networks of interactions between people [1]. In a SF network the probability distribution f (k) for a node to have k links to other nodes follows a power law,

$$f(k) \sim k^{-\gamma} , \tag{1}$$

where γ is a parameter that describes the abundance of the hubs, i.e., nodes of the network with large degree of connectiveness. Many unusual properties of SF networks have been attributed to distribution (1).

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1 Textfassung eines Vortrages, der am 1. April 2006 auf der Veranstaltung „Soziale Netzwerke" der DGS-Sektion „Modellbildung und Simulation" am Max-Planck-Institut für Gesellschaftsforschung in Köln gehalten wurde.

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(2) Typically, although extreme ideologies are originally advocated by very small fringe groups or even just a few "fanatics," experience over the past several decades indicates that such ideologies may continue to survive and even thrive over time scales that may be very large.

It is, therefore, clearly important to understand the role of the interactions network on the opinion of a population, and how it affects such antisocial behavior as terrorism. Moreover, it is equally important to understand the conditions under which extreme ideologies can thrive and survive for a long time. If such understandings can be developed, they may help in designing effective ways of confronting and addressing the problem of extreme ideologies.

In this paper we carry out computer simulations of a model in order to better understand the phenomenon of the spread of extreme ideologies in a society. The model is used to study how the opinions of various segments of a population may be influenced by the interactions among individuals, and how the connectivity of the interactions network influences the survival or disappearance of an opinion. In particular, we are interested in learning whether it is possible for a few fanatics to influence a large population and, if so, what factors control the phenomenon and may prolong its life time. To do so, we represent the network of interactions between people by a SF network [1] and study various scenarios that may affect the dynamics of the spreading of an opinion in a population.

The phenomenon that we study, and the model that we develop for it, belong, in principle, to a general class of problems that describe various epidemic processes. In particular, our model and work are motivated by the study of Castillo-Chavez and Song [2] (see below). Great efforts have been devoted for decades to understanding how certain epidemic diseases, such as HIV, spread throughout a society [3,4]. In particular, the so-called SIS (susceptible-infected-susceptible), SIR (susceptible-infected-removed), and SEIR (susceptible-exposed-infected-recovered) models have been developed and studied either in terms of differential equations that describe the rate of change of each group of the population, or in discrete forms on regular lattices, such as the square lattice. The long-term dynamics of these models, when studied in terms of differential equations (which represent a type of mean-field approximation) or on regular lattices, is relatively simple [5] and can be expressed in terms of two fixed points: Either the disease dies out, or a stable equilibrium is reached whereby the disease is endemic. A threshold condition determines which of the two fixed points is stable. More complex behavior may arise when, for example, the model contains a seasonal forcing. Generalizations to models in which the ill individuals have a continuum of states have also been made [6].

More recently, a few of such models have been examined in complex networks in order to understand some social phenomena. In particular, Zanette [7] examined the dynamics of an epidemiclike model for the spread of a "rumor" on a small-world (SW) network. A SW network is constructed starting from a one-dimensional lattice with periodic boundary conditions which, in effect, make the lattice a ring, where each node is connected to its 2k nearest neighbors, i.e., to the k nearest neighbors clockwise and counterclockwise [8]. To introduce disorder into the network, each of the k clockwise connections of each node i is rewired with a probability q to a randomly-selected node j that does not belong to the "neighborhood" of i. In this way, the lattice contains shortcuts between distant nodes. Zanette [7] showed that his model exhibits a transition between regimes of localization and propagation at a *finite* value of the network randomness q. Somewhat similiar work was carried out by Shao et al. [9] who studied how "blackmail" propagates in a SW network. In contrast, Pastor-Satorras and Vespignani

[10] showed that a dynamical model of spreading of epidemics does not exhibit any threshold behavior when studied in a SF network, *in the limit of a network of infinite size*, hence demonstrating a crucial difference between spreading of an epidemic phenomenon in SW and SF networks, which is clerarly due to their completely different connectivity structures.

The plan of this paper is as follows. In the next Section we describe the model. Section III contains the results and a discussion of their implications.

II THE MODEL

In the model the entire population is divided into four fractions: The general population G, those portions of the population that are either susceptible to, or excited about, an opinion, which we denote, respectively, by S and E, and the fanatics F who always advocate an opinion. Initially, everyone belongs to G, except a core of fanatics which, unless otherwise specified, is assumed to be four (but can be generalized to any number), since the most interesting results are obtained with a few initial fanatics (see below). Then, people can change their opinions depending on the neighbours to whom they listen to. Members of the S, E, and F groups can convince people in the G group to change their opinion and become susceptible to the fanatics's opinion; members of the E and F groups can convince the S group to become E; members of the F group can convince the E members to convert to F , but members of the S, E, and F groups can also directly return to the general population G. The fanatics are created initially by some outside event which is not part of the model. All the opinion changes happen with a probability p that can have any particular value if there is any evidence for it. Such a model can be applied not only to terrorism and other extreme opinions, but also to any other social phenomenon for which there is a degree of enthusiasm, or susceptibility to, in a society.

A model of opinion dynamics was proposed recently based on the percolation model [11]. Another recent model [12] uses, similar to our work, SF networks, but its dynamics and the quantities that it studies are completely different from those of the model studied in this paper. The partition of the population and the probabilities of opinion change in our model are similar to the model of Castillo-Chavez and Song [2] who proposed a deterministic continnum model in terms of a set of nonlinear differential equations, given by :

$$\begin{aligned} \frac{dS(t)}{dt} &= \beta_1 CG - \frac{\beta_2 S(E+F)}{C} - \gamma_1 S \ , \\ \frac{dE(t)}{dt} &= \frac{\beta_2 S(E+F)}{C} - \frac{\beta_3 EF}{C} - \gamma_2 E \ , \\ \frac{dF(t)}{dt} &= \frac{\beta_3 EF}{C} - \gamma_3 F \ , \end{aligned} \tag{2}$$

where the various coefficients, âi and ãi , are constant, and C = S + E + F = 1 - G. Without loss of generality, one can set $\beta 1$ = 1 since, otherwise, it can be absorbed in the time scale. (Omitting the denominators in the above model does not change the results.) For comparison, the dynamics of the SEIR model is described by [5]:

$$\frac{dS(t)}{dt} = \mu G - (\mu + \lambda)S \, ,$$
$$\frac{dE(t)}{dt} = \lambda S - (\mu + \sigma)E \, , \tag{3}$$
$$\frac{dF(t)}{dt} = \sigma E - (\mu + \nu)F \, ,$$

and, $\lambda = \beta$F , with the various parameters being constant. It is clear that the dynamics of our model is, in the continuum limit, much more complex than that of the SEIR model, even though they both are nonlinear. Castillo-Chavez and Song [2] studied their continuum model in detail. Similarly, the SEIR model was studied by, for example, Lloyd and May [5]. The models expressed by the sets (2) and (3) compute average behavior over the entire population and do not deal with individuals. Such approximations cannot answer, for example, the question of whether or how a few fanatics can convince an entire population about a certain opinion or proposition. They cannot also take into account the effect of the SF structure of the interaction network between people. Discretizing the model using a regular lattice, such as a square lattice, is also not realistic because the range of the interactions in such networks is limited. Instead, networks [1] between people or computers are described better as scale-free, and a network of the Barabási-Albert (BA) type is the most widespread. This is a complex network in which the probability distribution for a node to have k links to other nodes follows Eq. (1) with γ= 3. In such networks, a few people (nodes or hubs) have many connections, most people have rather few, and there is no sharp boundary between these extremes. We note that power laws also hold for the probability of terror attacks [13].

In this paper we simulate and study the model that we described above in the BA network which, to our knowledge, has never been done before on either the SW or SF networks. The BA networks are built by starting with four nodes (people) all connected to each other. Newcomers then join the network one after the other by connecting to the already-existing four members, with a probability proportional to the number of connections the member already has. In our study we use two BA types of SF networks. One is the hierarchical network with directed connections [14,15], which is a history-dependent network in the sense that a member only listens to and can be convinced by the four people who joined earlier and were selected by the member. The four people, who are higher in the hierarchy than the new member, do not listen to the new network member (that is, they do not change their opinion as a result of talking to the new network members). This is presumably the way a group with a rigid hierarchical command structure operates. An example, in the political arena, is provided by the communist parties in China and in the old Soviet Union. Thus, one has a hierarchy determined by who joins the group ?rst. The second type of the network that we use is symmetrical in the sense that all the connected members may influence each other, which is the way a group with a ?exible command structure and spread out throughout the globe may operate, so that even if the top leaders (the original fanatics) are eliminated, the group and its influence on people's opinion may live on. We have already seen examples of such groups in the Middle East and Latin America.

To simulate our model on a SF network, and to do so in a way that corresponds to continuum model of Castillo-Chavez and Song [2], we adopt the following rules:

$$G \rightarrow S \text{ with probability } \beta_1, \text{ if the neighbour is } S, E, \text{ or } F\ ,$$
$$F \rightarrow G \text{ with probability } \gamma_3\ ,$$
$$E \rightarrow F \text{ with probability } \beta_3/C, \text{ if the selected neighbour is } F; \text{ and } E \rightarrow G \text{ with probability } \gamma_2\ ,$$
$$S \rightarrow E \text{ with probability } \beta_2/C, \text{ if the selected neighbour is } E \text{ or } F; \text{ and } S \rightarrow G \text{ with probability } \gamma_1\ .$$

Thus, no person is convinced by an empty neighbour to change opinion. In this paper we simulate the behavior of two different systems, hierarchical and symmetric. In one, we assume that, $\beta_i = \beta_i =$ p (i = 1, 2, and 3), as one main goal of this paper is to study the effect of a few well-connected fanatics on the opinion of an entire population. In the second case, we allow $\beta_i \rightarrow \neq \beta_i$, and study several cases that we believe may yield interesting results and insights into the behavior of the phenomenon. We use an SF network of the BA type and, thus, the exponent γ in Eq. (1) takes on a fixed value of 3. The average connectivity ‹k› of the SF network that we use is, ‹k› = 8. We will not consider any other value of γ in the present paper.

Since the behavior of the population depends on the individuals' opinion and not just on their sum over all the lattice sites, sequential updating was used to simulate the model in both types of the network. We start with four fanatics on the network core while everybody else belongs to the general population G. We assume that the initial four fanatics are charismatic leaders forming the initial core of the network and, thus, becoming well-connected later. We also consider the cases in which the number of the initial fanatics is less than four (see below). Except when indicated otherwise, we use in all cases a single realization of the system. The reason for doing so is that we are not interested in the average behavior of all societies. Some societies are more susceptible to extreme opinions or ideologies than others, whereas averaging the results over many realizations (populations) might mask the results particular to a given population.

III RESULTS AND DISCUSSION

Figure 1 shows the results using the hierarchical network. Here, we used the probability p = $\beta_i = \beta_i$ =1/2. It indicates that in the ?rst few time steps a few fanatics can convert more than a million people to being susceptible to their ideology in a population of 25 million, even though the number of the (converted) fanatics actually falls down in the ?rst few steps. The E and F groups grow to much smaller percentages. Finally, the three groups, S, E, and F vanish, and everybody returns to the general population G. However, the S and E groups can survive much longer than the original fanatics; it is even possible that the fanatics die out accidentally after three time steps. Nevertheless, the avalanche that they set in motion stays on for a long time, which is in fact a wellknown phenomenon for many extreme ideologies or groups that believe in them.

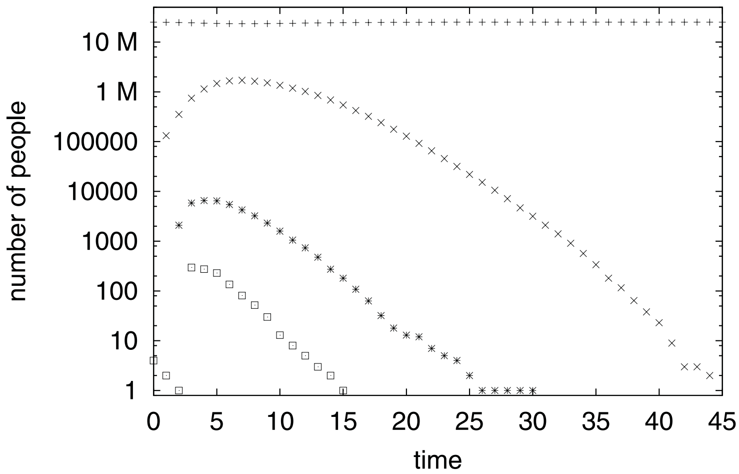

Figure 1: Evolution, from top to bottom, of the general (+), the susceptible (×), the excited (∗), and the fanatic population (squares) in the hierachical network. The total population is 25 million; the vertical scale is logarithmic, and $p = \beta_i = \gamma_i = 0.5$.

The survival of the S and E groups, instead of their eventual extinction in the hierarchical networks that Fig. 1 indicates, is possible in the symmetric network. This is shown in Fig. 2. For a probability $\beta_i = \gamma_i$ = p =1/2 to return from the S, E, and F groups to the general population G, the fanatics decrease from 4 to 2 in the first time step and vanish afterwards; nobody becomes excited, but up to 100 people become susceptible for some time, which is indicated by the continuous curve in Fig. 2. If, however, we reduce from 1/2 to 0.1 the probabilities γ_i of returning from the S, E, and F groups to G, then all the four populations (shown by symbols in Fig. 2) survive as large fractions of the total population. If we further reduce the return probabilities to 0.01, we will obtain the same survival pattern (not shown).

The question of survival of the susceptible people (spread of the opinion) appears to depend on the value of γ_i and on whether or not $\beta_i = \gamma_i$. We also find that if we hold all the β_i fixed, and vary γ_i, we obtain a type of transition in the behavior of the system in the following sense. As already shown, for low values of γ_i (for example, γ_i =0.1) the susceptible people always survive, while for large values (for example, γ_i = 0.5) they always die out. We find that there is a critical value γ_c of γ_i in the symmetric model at which the susceptibility dies out sometimes (that is, in certain realizations of a population) but survives at other times (in other realizations). We have determined this critical value to be, $\gamma_c \approx 0.43$. At this value a finite number of susceptible people survive in one realization, while dies out in another, albeit in a complex and seemingly oscillatory pattern.

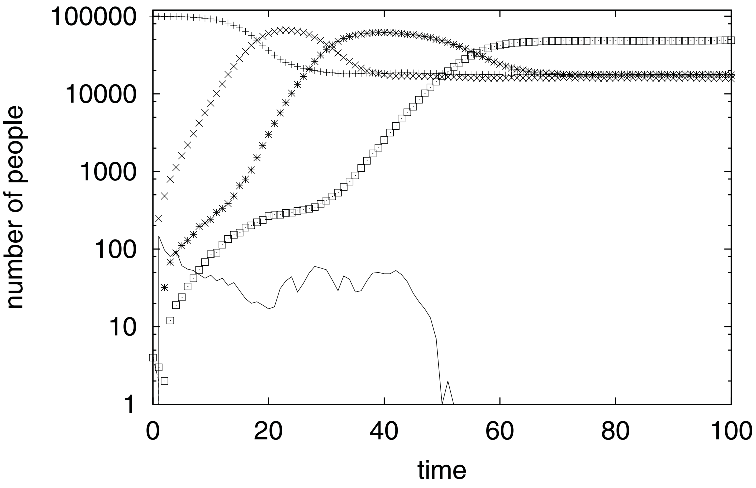

Figure 2: Symmetric network with 10^5 people: With $p = \beta_i = \gamma_i = 0.5$ the number of susceptible people (curve) first grows and then dies out. If, on the other hand, the three γ_i are reduced to 0.1, the G (+), S (×), E (∗) and F (squares) groups all become roughly equal and do *not* die out.

The mutual reinforcement of opinions in symmetric networks, which is impossible in the hierarchical networks, greatly increases their spread in a society. For the hierarchical network even with the reduced probability $p = \beta_i = \gamma_i = 0.1$ everybody becomes normal (returns to the general population) after some time, i.e., stops believing in the fanatics' opinion.

For a fixed set of the parameters away from the above transition point, the fate of the susceptible people (that is, survival as opposed to decay and eventual vanishing) is the same in every realization of the symmetric network. But, the pattern of the fluctuations in the number of such people, and the time scale over which it may vanish, might be quite different. The question, then, is whether one might have some type of universal data collapse for all values of the parameters. We investigated this issue by carrying out extensive simulations with the symmetric model, using several values of $p = \beta_i = \gamma_i$, and summing the results over 10^3 realizations of the network. Figure 3 presents the results where the time has been rescaled to pt. Scaling and data collapse hold roughly for small values of p. This implies that for small p a change in all the transition probabilities is merely a change in the time scale, which appears to be plausible.

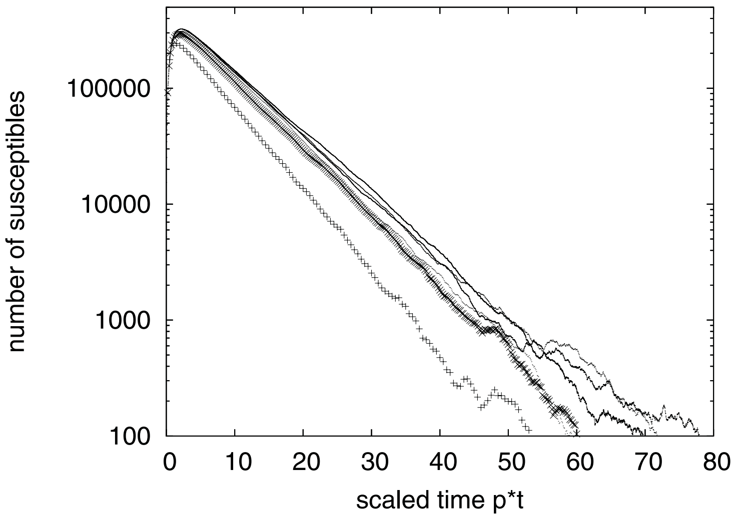

Figure 3: Data collapse and scaling for the number of susceptible people versus the rescaled time pt, where $p = \beta_i = \gamma_i$. The results present the sum over 10^3 realizations of the symmetric networks of 10^5 people for $p = 0.5$ (+), 0.2 (×), 0.1, 0.05, 0.02, and 0.01. Data collapse holds roughly for small p.

The great influence of the four initial fanatics stems from the fact that the founders of the network (where the fanatics reside), numbers 1, 2, 3, and 4 in its history, are well connected. The later a person joins the interaction network (higher membership numbers), the smaller is, in general, the number of connections and, thus, the influence. This effect is demonstrated in Fig. 4 where we show the results for the hierarchical model with 25 million people. The top curve shows how up to 5% of the population becomes susceptible under the influence of numbers 1, 2, 3, and 4 (taking p $=\beta_i=\gamma_i=1/2$). If, instead, network members 11, 12, 13, and 14 are taken as the original fanatics (which are not as well-connected as those in numbers 1, 2, 3, and 4), then less than 1% of the population becomes susceptible (second curve from above in Fig. 4). The lower curves show analogously how the influence of the initial four fanatics is reduced if we take them as the four that follow numbers 10^2, 10^3, ..., 10^7 in the networks of 25 million people (nodes). Due to the non linearity of the model, the initial concentrations, E(0), S(0), and G(0), are important to its dynamics and therefore ,we have considered their effect. We studied the case in which everybody outside the initial core was initially, (a) susceptible (S); (b) excited (E); (c) fanatic(F), or (d) belonged to the general population (G), as before. The four core members were always the fanatics (F). We studied the model in the hierarchical SF network with 35 million nodes ,with the probability p$=\beta_i=\gamma_i=1/2$. Except when the entire system (aside from the core four fanatics) is composed of susceptible people, the fraction of the S population first increases, reaching a maximum, but then decreases essentially exponentially ,even when everybody in the network is initially a fanatic. A similar phenomenon happens to the excited population E. Such a behaviour will not change if the probability p is varied. In various simulations, the excited and susceptible populations eventually vanish. Even the population of the fanatics eventually vanishes in the hierarchical structure. The only effect that the probability of conversion p has is the time scale over which the populations of the excited, fanatic, or susceptible people eventually vanish. Therefore, in a hierarchical structure everybody will eventually go back to the general population, and will neither be susceptible to nor excited about the opinion originally advocated by the core fanatics. The most important aspect of these results is the robust nature of the model: Regardless of the initial composition of the network, the E, F, and S segments of the population eventually die out, and everybody returns to the general population.

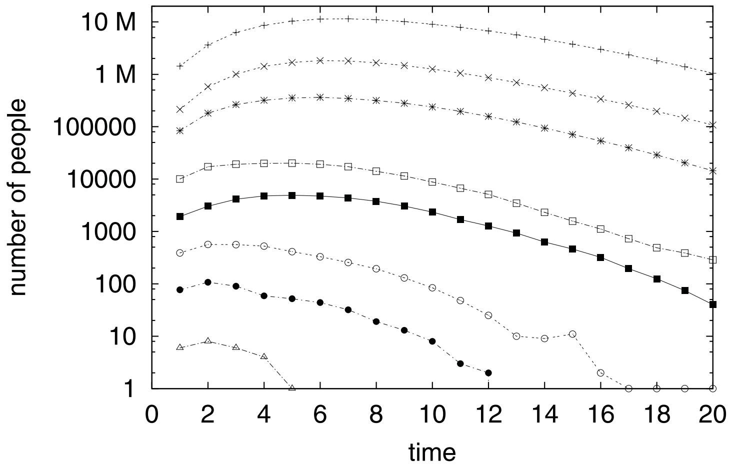

Figure 4: The sum over 10 hierarchical networks of 25 million people each. The four initial radicals joined the network, from top to bottom, as numbers 1, 2, 3, and 4; 11, 12, 13, and 14; then 101, 102, 103, and 104, until 10000001, 10000002, 10000003, 10000004 for the lowest curve. Latecomers are seen to have little influence. The results are for $p = \beta_i = \gamma_i = 0.5$.

To see whether the connectivity and hierarchical structure of the network make any difference, we repeated the simulations using the symmetrical SF network in which the influence of two connected nodes on each other is mutual, again with $p = \beta_i = \gamma_i = 0.5$. The susceptible population in this case decreases over time, but the reduction, rather than being exponential, is rather complex and resembles a seemingly oscillatory pattern, which is due to the feedback mechanism which is present in the symmetrical network.

All the results presented so far were obtained with four initial fanatics. What happens if we have fewer initial fanatics? We carried out simulations with the symmetric model with only one initial fanatic. Since there are four sites in the network's core but only one initial fanatic, we repeated the simulations four times using the same network, each time starting with the fanatic in a different core site. We found that there can be two distinct cases: In one case the entire population becomes normal after the first time step, while in the other three cases one obtains the same general patterns as before. Varying values of the parameters does not change this pattern, namely, either the entire population becomes normal after the first or first few steps, or one obtains the same general patterns as those obtained with four initial fanatics.

How would the above results differ if we carried out the same simulations but on the square lattice, which has a very limited interaction range and fixed (and low) connectivity (4 neighbors) ? We find that in an $L \times L$ square lattice with four initial fanatics the extreme opinion does not spread at long times, regardless of the values of β_i and γ_i, which is in contrast with what we find in the SF networks. However, if we start with an entire line of size L of fanatics, we recover the SF-type behavior, namely, the extreme ideology may or may not survive at long times, depending on the values of the parameters β_i and γ_i. Therefore, there is a fundamental difference between the spread of an extreme opinion or ideology in a network of people with the SF structure, and one with the severely restricted topology of a square lattice and similar networks, hence demonstrating the significance of the range of people-to-people interactions.

BA networks have a percolation threshold [10] vanishing as 1/log(N) and thus purely geometrically information can always spread through a large population. But this is only a necessary and not a sufficient condition for opinion spreading; as Fig.1 and the lower curve in Fig.2 indicate, opinions may also die out instead of spreading.

SUMMARY

Although some previous works [16] had investigated the spreading of a state shared by a number of agents, none was in the context of the type of model that we study in this paper, namely, a fourcomponent interacting system with the interactions being via a SF network. In addition, we ?nd important differences between the influence of the hierarchical and symmetric networks on opinion dynamics. If the followers listen to the leaders but not the other way around (hierarchical interaction network), then the ideas of the leaders will die out. In the political arena a good example is provided by the communism as advocated by the Soviet Union in which there was a rigid structure imposed by the communist party and its top leadership.

If, on the other hand, the leaders also listen to their followers, then their opinions may last long, even if the leaders themselves are eliminated. The closer the leaders are to the core of the network (the best connected part of the network), the higher is their impact on the general population. Examples, in the political arena, are provided by extremist groups in the Middle East and Latin America. This phenomenon is also similar to Ising magnets studied on SF networks [17], but different from other models of opinion dynamics [15] in the sense that, the hierarchical network structure yields results that are very different from those obtained by the undirected, symmetric networks.

We regard the possibility of a few people influencing a large fraction of the population, and the persistence of an opinion in a symmetrical SF network but not in a hierarchical one, as the main results of this paper. Further predictions of the model, a comparison with its continuum counterpart, and its simulation on regular two-dimensional lattices, are reported elsewhere [18].

We thank Shlomo Havlin for suggesting that we study the behavior of the system by holding one set of the parameters (the β_i) fixed and varying the other one (the γ_i).

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