Physica A 443 (2016) 316–323

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Social consensus and tipping points with opinion inertia

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HIGHLIGHTS

- Socio-psychological “costs” involved in changing one’s opinion has a strong impact on tipping points.
- A small minority opinion can tip over the population if its inertia outweighs that of the opposing opinion.
- We developed a semi-analytical approach which yields an upper bound for the critical minority size.
- In low-dimensional spatial graphs, the opinion domain evolution with inertia can exhibit coarsening.

ARTICLE INFO

Article history:
Received 15 February 2015
Received in revised form 29 June 2015
Available online 28 September 2015

Keywords:
Opinion dynamics
Social networks
Influencing
Tipping points
Opinion inertia

ABSTRACT

When opinions, behaviors or ideas diffuse within a population, some are invariably more *sticky* than others. The stickier the opinion, behavior or idea, the greater is an individual’s inertia to replace it with an alternative. Here we study the effect of stickiness of opinions in a two-opinion model, where individuals change their opinion only after a certain number of consecutive encounters with the alternative opinion. Assuming that one opinion has a fixed stickiness, we investigate how the critical size of the competing opinion required to tip over the entire population varies as a function of the competing opinion’s stickiness. We analyze this scenario for the case of a complete-graph topology through simulations, and through a semi-analytical approach which yields an upper bound for the critical minority size. We present analogous simulation results for the case of the Erdős–Rényi random network. Finally, we investigate the coarsening properties of sticky opinion spreading on two-dimensional lattices, and show that the presence of stickiness gives rise to an effective surface tension that causes the coarsening behavior to become curvature-driven.

1. Introduction

Social networks represent potent structures on which opinions and behavior diffuse, and on which tipping points [1] in the adoption of opinions and behavior arise. A number of theoretical studies investigating the diffusion of ideas, opinions, or behavior, have focused on understanding how a small fraction of initiators [2–4] or committed proselytizers [5–10] of an idea can tip over the entire network to adopt the same. Furthermore, within these studies, various sources of competition to the spread of an idea have been considered—for example, a competing idea that is spreading over the network, or a

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http://dx.doi.org/10.1016/j.physa.2015.09.081
0378-4371/

bias external to the network that is trying to suppress the spread of an idea. More pertinently, however, the tendency of individuals themselves to be pliable to change is dynamic and could be dependent on their activity. In particular, individual behavior itself is subject to some inertia that opposes any change in the beliefs or opinions adopted by the individual [11]. A well known example of such inertia is the phenomenon of *confirmation bias* in social psychology, where individuals tend to favor beliefs that conform to their currently held position. Overcoming such individual inertia to change is therefore a primary consideration in campaigns for public opinion change [12].

Motivated by this phenomenon, we study a theoretical model of opinion change where individual opinion change depends on the current state of the individual as well as the recent history of the opinions she has encountered in interactions with her neighborhood. Specifically, we assume that there are two opinions vying for adoption on a social network, and each individual requires a pre-defined threshold number of interactions with the alternative opinion, before switching to it. Thus each opinion is *sticky* to its respective extent [12]. Furthermore, in an attempt to capture the effect of confirmation bias, we posit that an individual's memory of a stream of encounters with the alternative opinion is erased by a single interaction in which he encounters his currently held opinion. There is some precedent to studying such a memory-based model of switching between states. Dodds and Watts [13] studied a model of disease contagion where a susceptible person became infected only when his interactions with infected neighbors within a certain prior time window had led to a pre-defined infection–dosage threshold being exceeded. More pertinently to the current study, Dall'Asta and Castellano [14] studied a variant of the Naming Game with two pure opinions, where an individual switches to the intermediate state only when the number of times he has encountered the opposing opinion exceeds some pre-defined threshold. Our model thus is a special case of Ref. [14] where the memory window is exactly equal to the threshold, and where no intermediate state is present. In contrast to the work done in Ref. [14], here our focus is to look at the fraction of initiators required to bring about a tipping point. The effect of stickiness has also been studied in the context of the Naming Game in Ref. [15] and more recently in Ref. [16]. In these studies, the stickiness parameter quantifies the probabilities with which a node in a mixed-opinion state rejects a pure state that it encounters in an interaction with its neighbors. The introduction of the stickiness parameter for nodes in the mixed-opinion state, gives rise to a phase transition between a regime where the consensus states are stable (when stickiness is low) to one where the consensus states are unstable and the system gravitates to a stable state with a non-zero density of mixed-opinion nodes.

A recent work [17] has studied a variant of the SIR model where the infection probability is a function of the number of infectious neighbors, and parametrized by two parameters that they designate as stickiness and persistence. Despite the nomenclature, the term stickiness is utilized in Ref. [17] to designate the slope of the infection probability of a susceptible node as a function of the size of its infected neighborhood, and therefore bears little similarity to the context that we study. Finally, recent empirical findings [18] demonstrate the dependence of social network properties on cultural attributes of the population, suggesting that stickiness could also be similarly influenced by cultural factors.

2. Description of model

Here we define the microscopic rules of our model. We assume that every individual on a social network initially adopts one of two opinions, which we designate A and B. The fundamental mechanism in our model for the change in individual states is the interaction of pairs of individuals, which represent speaker–listener pairs. In each such interaction, the speaker conveys his opinion to the listener, and in response to this conveyed opinion, the listener changes his state or continues to hold the same state depending on the rules of the model. We elaborate on these rules in the next few lines. First, each opinion has a pre-defined *stickiness*, designated as w_A and w_B respectively. The stickiness of an opinion represents the inertia present in an individual adopting that opinion, to change her state. In terms of the model, the stickiness w_A (w_B) of an individual in state A (B) is the number of consecutive times she requires to hear the opinion B (A), before she switches her opinion to B (A). Thus, we can assume that each individual keeps a counter dedicated to counting the number of times she encounters the alternative opinion, which resets to zero either when the required number of consecutive interactions of the alternative opinion are heard, or whenever the current opinion is heard. Note that in the former case, the counter also switches the opinion that it is keeping track of. In our current model implementation, we assumed that exposure to a different/same opinion only impacts the individuals' counter when their role is the listener in a pairwise interaction. Naturally, one may consider the scenario where both the speaker's and listener's counters are affected by the interactions (i.e., the speaker can also be reinforced in her view). We did some explorations on this generalization of the model, and have found that there are no qualitative differences in the results.

In summary, the model dynamics proceeds as follows. The individuals (nodes) in the network are initially assigned one of the two opinions such that we have prescribed fractions p_A and $p_B = 1 - p_A$ of nodes in states A and B respectively. Then at each microscopic time step, a random node is chosen from the system and designated as the speaker. A random node is selected from among the speaker's neighbors and designated as the listener. If the listener's opinion is the same as the speaker's, it's progress towards switching is reset to zero. If the listener's opinion is different from the speaker's, the listener's count towards switching increases by one. If the listener's count becomes equal to it's opinion's stickiness, it adopts the alternative opinion and begins a fresh count. We assume that N such microscopic time steps constitute unit time, where N is the network size. Thus, the event that a node is selected as a speaker is a Poisson process with rate 1.