Opinion Formation under the Two-Step Flow Model and the GR Game Framework

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Abstract
The Gür game, an artificial game, associates voters in the game with finite state automata and a moderator with a reward function. The "two-step flow communication model", a hypothesis based on empirical studies and then popular in marketing and diffusion research, addresses that audience may not receive the influence from the mass media directly, instead mediated by "opinion leaders" to their followers. In this paper, we seek to discover the roles of opinion leaders and individuals following one or more opinion leaders with distinct opinions under the Gür game framework and the two-step flow model. Each follower is associated with a finite state automaton to reflect the state of mind. An opinion leader has a reward function to predict the probability of any follower changing the state of mind after he/she updates status or comments on an issue. Different from the standard Gür game model, multiple moderators are involved in the proposed model.

We examine a scenario with two groups led by two opinion leaders with opposite opinions on an issue, and explore the parameters of group size, the role of overlapped followers and opinion convergence speed. We discuss when a group led by a dominated and opinionated opinion leader converges faster than a group with a weak leader, how the overlapped followers influence the group with a weak leader. In addition, we explore how parameters mentioned above influence opinion formation when a smaller group is formed inside a larger group in the Gür game framework.

Keywords: Opinion formation, Gür game, Two-step flow communication model

Introduction

People usually hold opinions on numerous topics, from politics to restaurants, new products and so on. These opinions can be either the results from their experience or influenced by others. With the development of Web 2.0 platforms and the popularity of social medias, more and more people use social media to interact with friends, form friendships, share their interests and opinions on some issues, and so forth. By interacting with each other, people's opinions might be influenced.

In this paper, we seek to discover the roles of opinion leaders and individuals following one or more opinion leaders with distinct opinions in the media influence under the Gür game framework and the two-step flow model. The two-step flow model, is a one-way information/influence moving process as stated by Burt (1999) and has no detail in the structure of influence networks. We are interested in modelling how individuals follow one or more opinion leaders on an issue (Figure 1). An opinion leader can be also a follower of other opinion leaders. We start with a simple scenario with only two groups led by two opinion leaders with opposite opinions on an issue, and explore the parameters of group size, the role of overlapped followers, opinion leaders' prediction on the probability followers changing minds, and opinion convergence speed. In order to consider the opinion leaders' prediction on the probability followers changing their minds, we take advantage of the Gür game in which eventually there will be approximately some fraction of followers holding the same opinion with their leader. We discuss when a group led by a dominated and opinionated opinion leader converges faster than a group with a weak leader, how the overlapped followers influence the group with a weak leader. To start with, we review the two-step flow model proposed by Katz and Lazarsfeld (1955), and the Gür game introduced by Tsetlin (1973).

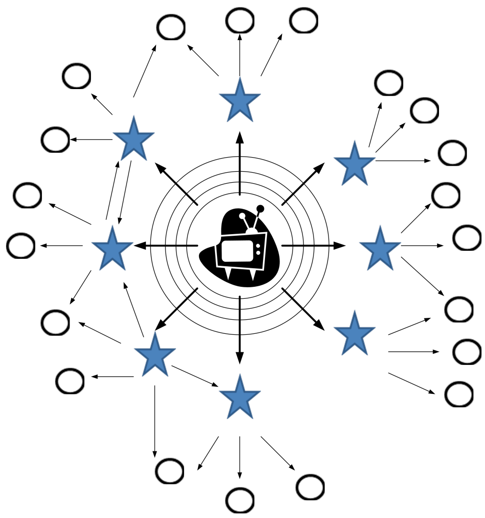

Figure 1: A schematic diagram of opinion leaders and followers where stars and circles represent opinion leaders and their followers respectively.

Two-Step Flow Communication Model

The two-Step flow communication model, a hypothesis based on empirical studies, proposed by Katz and Lazarsfeld (1955), sought to address the influence from the mass media may not be received by audience directly, instead mediated by "opinion leaders" (Merton, 1957) to their followers as illustrated in Figure 2. "Opinion leaders" was defined as "individuals who were likely to influence other persons in their immediate environment". They showed the analysis in various decision-making scenarios ranging from political campaigns to movie-going, fashion etc. that individuals may be influenced more by group leaders than the mass media. It is worth noting the model emphasized that *opinion leaders are to be found on every level of society and presumably, therefore, are very much like the people whom they influence* (Katz, 1957). In other words, opinion leaders can be public figures such as journalists or celebrities, or ordinary people who are more exposed to mass media compared with their relatives, co-workers and friends. After the introduction of the two-step flow of communication, it started to gain increasing interest in some communities such as marketing and diffusion research (Watts & Dodds, 2007), etc. Burt (1999) commented that *the "two-step flow" of communication - a process of information moving from the media to opinion leaders, and influence moving from opinion leaders to their followers - became a guiding theme for diffusion and marketing research.*

However, as Watts and Dodds (2007) showed that the roles of opinion leaders, and the network structure and how exactly opinion leaders influence their followers in the two-step flow model are not clear. By conducting a series of simulations, Watts and Dodds (2007) concluded that generally most of social change is driven by easily influenced individuals influencing other easily influenced individuals not by opinion leaders, and only under some exceptions opinion leaders participate more in triggering large-scale cascades. Not surprisingly, the two-step flow of communication hypothesis is not fully supported by the simulations conducted by Watts and Dodds (2007), because the set-up of simulations is totally different from the description of the two-step flow model or more precisely since the characteristics of opinion leaders cannot be reflected in the simulations. Wu et al. (2011) re-examined the two-step flow model using the feature of Twitter known as "Lists" to distinguish between elite and ordinary users, and found that Twitter data considerable agreed with the two-Step flow model. But it's important as Watts and Dodds (2007) argued that the importance and necessity of assumptions regarding the rule of interpersonal influence (the details of who influences whom and how), the structure of influence networks and so on are required for validation rather than just a hypothesis according to empirical studies.

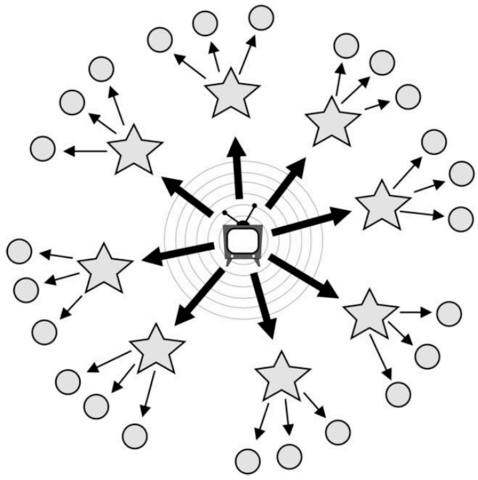

Figure 2: The schematic diagram of the two-step flow of communication hypothesis where stars and circles represent opinion leaders and their respective followers respectively. Figure extracted from (Watts & Dodds, 2007).

Gür Game

The Gür game, a fascinating artificial game introduced by Tsetlin (1973), associates agents in the game with finite state automata. Imagine that we have a moderator and many voters in a room to play the game. Each voter is aware of the moderator only. Voters do not communicate with each other. On each round of the game, the moderator asks voters to vote yes or no simultaneously and the moderator counts the fraction f of yes votes. A reward function $r(f)$ only known by the moderator, is generated to reward or penalize each voter independently. The reward function is bounded $0 \leq r(f) \leq 1$. At the end of each round, every voter is independently rewarded (with probability $r(f)$) or penalized (with probability 1-$r(f)$) one dollar regardless what he votes. Each voter decides what to vote on the next round based on if he is rewarded or penalized on the current round. After enough trials, the fraction of yes votes is exactly f^* in which the maximum of the reward function occurs. No matter how many voters there are, approximately f^* of them vote yes after enough trials. A reward function can be any function. It is can uni-modal, discontinuous, multi-modal, etc. A typical reward function is shown in Figure 3.

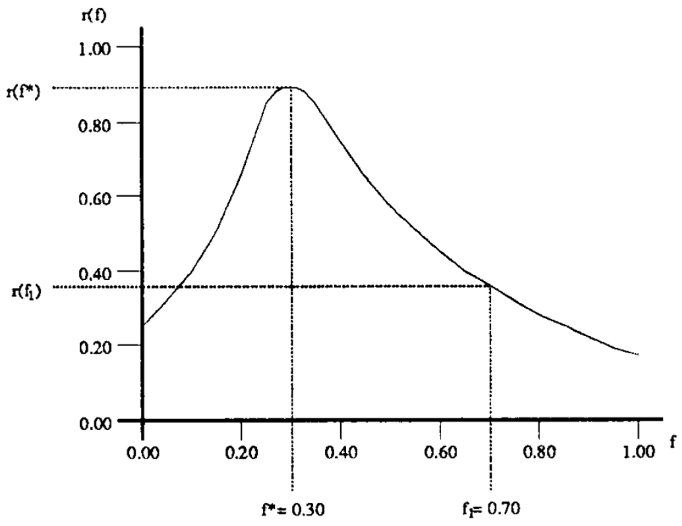

Figure 3: A typical reward function. Figure extracted from (Tung & Kleinrock, 1993).

Let's start the Gür game with a simple automaton with two states (1 and -1), called $L_{2,2}$ (Tsetlin, 1973). The state diagram is shown in Figure 4. If the current state is 1, the automaton outputs A_1; otherwise, it gives output of A_0. If the automaton is rewarded, it stays in the same state in the next round. If the automaton is penalized, it changes the state in the next round. Design of the $L_{2,\,2}$ faithfully addresses the encouragement to choose an output producing a reward and the discouragement to choose an output producing a penalty.

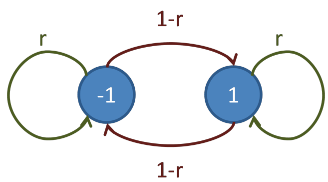

Figure 4: Automata design of $L_{2,\,2}$. Figure redrawn from (Tselin, 1973).

To generalize the $L_{2,\,2}$ automaton, Tsetlin (1973) gave the automaton more than two state, the automaton $L_{2,\,2n}$ with 2n states, said has a memory size of n as shown in Figure 5.

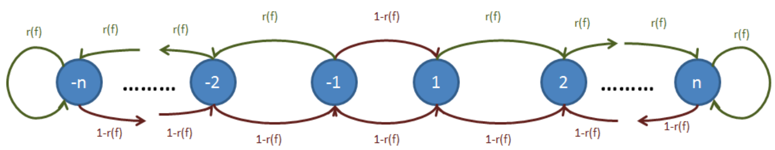

Figure 5: Automata design of $L_{2,\,2n}$. Figure redrawn from (Tselin, 1973).

Similar to the $L_{2,2}$ automaton, if its current state is the negative numbered state, A_0 is output; otherwise A_1 is given. The $L_{2,2n}$ automaton follows the following state transition rules:

if an automaton is rewarded

    if its current state is n or -n,
        stay in the same state
    else if $1 \leq$ current state, $i \leq$ n-1,
        next state = i +1
    else if -n+1 $\leq$ current state, $i \leq$ -1,
        next state = i -1
else
    if current state is -1,
        next state = 1
    else if current state is 1,
        next state = -1
    else if $2 \leq$ current state, $i \leq$ n,
        next state = i -1
    else if -n $\leq$ current state, $i \leq$ -2,
        next state = i +1

With the Gür game further discussed by Tung and Kleinrock (1996), it starts to gain increasing interest in some communities such as wireless sensor networks (Iyer & Kleinrock, 1996; Liu et al., 2011; Zhao et al., 2006), etc. Due to the description of the game, people employ only one moderator in a system, which implies only one reward function is invoked during the computation. However, the Gür game is not restricted to have only one moderator in a system. For example, we can designate leaders of different communities as the moderators in networks and nodes in the network are allowed to join different communities.

Opinion Formation Model Under Two-Step Flow And Gür Game Framework

Opinion formation is a complicated process that cannot be easily predicted by a set of rules of individual minds. However for an opinion leader, he/she is able to know how well followers are convinced by him/her (followers do not necessarily agree on the leader) and membership of followers through conducting survey or long-term observation. Thus we perform an analysis on opinion formation based on the Gür game rather than defining a set of rules for individuals. The roles of opinion leaders and their followers can be represented as moderators and voters in the framework of the Gür game. Under the framework of the Gür game, each opinion leader is associated with a reward function that reflects the probability of each follower changing the state of mind after the opinion leader updates the status or commenting on an issue. Followers are considered as voters in the Gür game and associated with finite state automata that represent the state of mind of followers. As mentioned before, the proposed model uses the two-step communication flow model that means the influence only moves from opinion leaders to their followers and satisfies the rule of the Gür game that each voter is aware of the moderator only. Below we give a more detailed explanation how the proposed opinion formation model integrates with the Gür Game.

Integration with the Gür Game

To start, each opinion leader op_i is associated with a reward function $r_i(f_i)$ which is used for the probability that each follower will change the state of mind to believe his leader more firmly or not. A reward function $r_i(f_i)$ is generated to reward or penalize each follower independently and only known by the opinion leader op_i. At the time step j, the opinion leader op_i updates his status. op_i can predict the probability of each follower changing the state of mind based on the fraction of the number of followers who agree on his opinion, which collected at time step $j-1$. At the end of each round, each follower of op_i is independently rewarded (with probability $r_i(f_i)$) or penalized (with probability $1-r_i(f_i)$) regardless whether he agrees on op_i or not. In the scheme, a reward represents op_i 's comment or update on an issue matches the mind of a op_i 's follower who agreed on op_i or mismatches the mind of a op_i's follower who disagreed on op_i. Likewise a penalty represents op_i's comment or update on an issue does not matches the mind of a op_i's follower who agreed on op_i or matches the mind of a op_i's follower who disagreed on op_i.

Each follower is associated with a finite state automaton (as shown in Figure 6) as his or her states of mind. If a follower's current state is positive, he/she agrees the opinion leader op_i's opinion; if it is negative, he/she disagrees op_i. The more positive the current state is, the more the follower is convinced by op_i. The more negative the current state is, the less the follower is convinced by op_i. Each follower changes the state after his/her group leader updates the status or comments on an event or issue. If a follower receives a reward from his/her opinion leader, he will stay in the state n or $-n$ if he is in either of the states; otherwise, he will change the state from k to $k+1$ if the current state k is positive, or from k to $k-1$ if the current state k is negative. If a follower receives a penalty from his/her opinion leader, he will change the state to 1 or -1 if he is in either of the states; otherwise, he will change the state from k to $k+1$ if the current state k is negative, or from k to $k-1$ if the current state k is positive. Roughly, a follower changes the state of mind away from the center if he is rewarded, and toward the center if he is penalized.

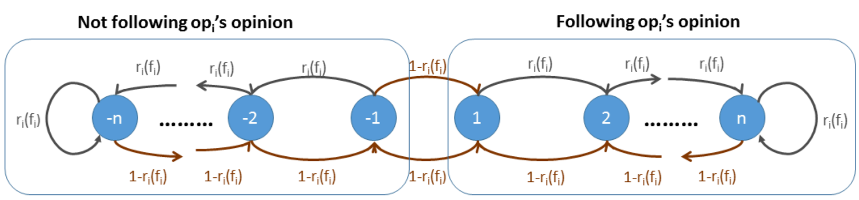

Figure 6: Using a finite state automaton to represent a follower's state of mind.

In summary, we sought to present how each follower is associated with finite state automata as shown in Figure 6. If each state is associated with a mind state and the positive states represent the faithful degree of agreeing on the group leader's opinion, a follower with the state n (Figure 6) can be considered as the most faithful to his leader's opinion. Similarly if the negative states represent the degree of disagreeing on the group leader's opinion, a follower with the state $-n$ can be regarded as the most non-faithful to his group leader's opinion. After a group leader updates the status or comments on an event or issue, his/her follower is independently rewarded (with probability $r_i(f_i)$) or penalized (with probability $1-r_i(f_i)$) regardless whether he agrees on op_i or not.

Case Studies

To examine the proposed framework, we start with a simple scenario, as shown in Figure 7, that two opinion leaders with opposite opinions on an issue have their respective followers and some followers join both groups. Then we discuss the scenario that a smaller group is formed inside a larger group, as shown in Figure 8. We investigate how the parameters of group size, the role of overlapped followers, the prediction of changing mind by opinion leaders, and opinion convergence speed influence opinion formation. The variables are defined as follows:

$S_{1,j}$: the number of op_1's followers at time j where op_1 is the opinion leader of group G_1.
$S_{2,j}$: the number of op_2's followers at time j where op_2 is the opinion leader of group G_2.
$S_{12,j}$: the number of individuals who are members of both groups G_1 and G_2 at time j.
$P_{1,j}$: the fraction of op_1's followers convinced by op_1, $0 \le P_1 \le 1$ at time j.
$P_{2,j}$: the fraction of op_2's followers convinced by op_2, $0 \le P_2 \le 1$ at time j.
P_1^*: the fraction of op_1's followers eventually convinced by op_1, equivalent to f_1^* in the Gür game.
P_2^*: the fraction of op_2's followers eventually convinced by op_2, equivalent to f_2^* in the Gür game
Y: the number of $op2$'s followers who only follow $op2$ but eventually convinced by op_1 at time j.

All the above variables can be functions of time. In other words, nodes can change their membership, a new node can join the system, and leaders' prediction varies by time. Note that the case studies below will be discussed under the condition that reward functions, $r_1(P_1^*)= r_2(P_2^*)=1.0$.

Case 1: Two groups with some common followers

To start, we assume the group G_1, as shown in Figure 7, converges first. If $P_2^*S_{2,j} > S_{2,j} - S_{12,j}\times P_1^*$, the group G_2 will not reach the optimal ($P_2^*S_{2,j}$) under the Gür game framework. Total number of people who eventually agree with op_1 is $P_1^*S_{1,j}+Y$ where $Y=(S_{2,j}-S_{12,j})\times(1-P_{2,j})$. Total number of people who eventually agree with op_2 is $(1-P_1^*)\times S_{1,j}+ P_{2,j}\times (S_{2,j}-S_{12,j}\times P_1^*)$.

If $P_2^*S_{2,j} \le S_{2,j} - S_{12,j}\times P_1^*$, the total number of people who eventually agree with op_1 is $P_1^*S_{1,j}+Y$ where $Y=(S_{2,j}-S_{12,j})\times(1-P_2^*)$. Total number of people who eventually agree with op_2 is $(1-P_1^*)\times S_{1,j}+ P_2^*\times (S_{2,j}-S_{12,j}\times P_1^*)$.

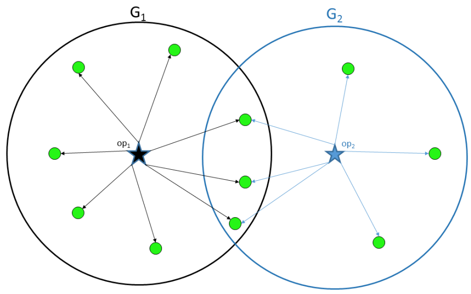

Figure 7: Two groups with some common followers where stars and circles represent opinion leaders and their respective followers respectively.

Case 2: A small group formed in a big group

Assume the group G_1, as shown in Figure 8, converges first. Total number of people who eventually agree with op_1 is $P_1^*S_{1,j}$. Total number of people who eventually agree with op_2 is $(1-P_1^*)\times S_{2,j}$.

Conversely, we assume the group G_2, as shown in Figure 8, converges first. If $S_{1,j}-P_2^*S_{2,j} < P_1^*S_{1,j}$, the group G_1 will not reach the optimal ($P_1^*S_{1,j}$) under the Gür game framework. Total number of people who eventually agree with op_1 is $(1-P_2^*)\times S_{2,j} + P_{1,j}\times(S_{1,j}-S_{2,j})$. Total number of people who eventually agree with op_2 is $P_2^*S_{2,j} + (1-P_{1,j})\times (S_{1,j}-S_{2,j})$. If $S_{1,j}- P_2^*S_{2,j} \geq P_1^*S_{1,j}$, the total number of people who eventually agree with op_1 is $(1-P_2^*)\times S_{2,j} + P_1^*\times(S_{1,j}-S_{2,j})$. Total number of people who eventually agree with op_2 is $P_2^*S_{2,j} + (1- P_1^*)\times (S_{1,j}-S_{2,j})$.

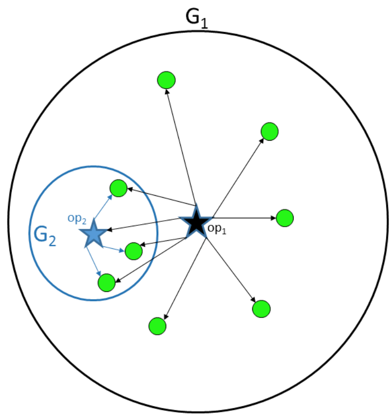

Figure 8: Two groups with some common followers where stars and circles represent opinion leaders and their respective followers respectively. G2 is in the G1.

Conclusions & Future Study

In this paper, we discussed the opinion formation in terms of the final number of each opinion leader's followers by taking advantage of the Gür game framework. Under the Gür game framework, each follower is associated with finite state automata as shown in Figure 6, and each state is associated with a mind state. Furthermore, two cases have been analyzed to better understand the applications of the Gür game in opinion formation.

In the future, we will conduct a series of simulations to validate the analysis and discover more in regard to the roles of reward functions of the Gür game and the number of mind states. The analysis and simulations for more than two groups will be conducted as well.

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