A Multi-Generational Social Learning Model: the Effect of Information Cascade on Aggregate Welfare

Marziyeh Barghandan, Mohammad Malekzadeh, Atefeh Safdel and Iren Mazloomzadeh
Department of Computer Engineering, Faculty of Engineering
Persian Gulf University
Bushehr 75169, Iran
mohmalekzadeh@pgu.ac.ir, {ma.barghandan & at.safdel & ir.mazloomzadeh}@mehr.pgu.ac.ir

***Abstract*- For the past decades, people combine both environmental learnings (observations) and social learnings (intercommunication links) in their decision process. People in the communities face limitations or conditions which have effects on their decisions. In this paper, we present a multigenerational social learning model to analyse a world with some limitations. Then we turn the world to a free world and people try to find correct decisions utilizing these changes. In the presented model, people make their initial decisions based on sequential decision model which leads them into the herd behavior. Then we change the world so that making connections with other communities is possible. We show how aggregate welfare will be improved when people use their observations, their new obtained information on social ties and their personality factors to review their current decisions. We also have a parameter in our model that examines the effect of personality factor value on the percentage of the correct decision among the communities. Our main results show when people use their obtained information rather than sticking to the herd behavior, the aggregate welfare will be better in the world, even if people use only their own observations.**

Index Terms–Herd Behavior, Social Learning Model, Decision-making Model, Information Cascade, Observation Learning.

I. Introduction

Today's people are connected to each other by the network. It becomes possible for them to influence each other's behavior and decisions. Depending on situations and conditions, people in different communities may use different decision-making models. Herd behavior [8, 17] and informational cascades [10] are two related concepts that mostly have been used for studying the decisions made by individuals. One of these models is Sequential Decision model which is used by individuals in society today [8].

In the sequential decision model, each decision maker looks at the decisions made by previous decision makers before taking her own decision. This is rational for her, because these other decision makers may have some information that is important for her, although it may result in an aggregate welfare loss [11]. The decision rules that are chosen by optimizing individuals will be characterized by herd behavior. However, people may change their behavior when some circumstances change; e.g. when person's position in the network is changed by new friendly links, or with the development of a new idea, or change in personal income.

People in the world are classified in the various communities based on different criteria, such as geographical location, their government and technologies that are used. Nowadays, new and affordable technologies are making information exchange easier between people who are not even within the same society. Therefore, this information could be used by individuals in other societies and geographical locations.

In this paper, each community of people will be named as a *tribe*. Our model assumes the world around us is composed of several isolated tribes. At first glance, people in each isolated tribe don't communicate with people in other tribes. We call this world as *isolated world*. We consider that all people in the world have to make a decision about a unique issue. In our model of isolated world, initial decision of each person is made according to the decision of the other members of her community. Finally, each tribe declares its own decision according to what the majority of people in tribe declared.

In the second step, we suppose that each person in the world can communicate with the other tribes and exchange information with people who live in those tribes. We call this world as *aware world*. Therefore, everyone will have the chance to change their decision by using information obtained from other tribes. A person can decide to change or not to change her decision, after knowing the other tribes' decision.

We expect that there may be a change in people's decisions depends on some factors such as: the number of their friends, their current decisions and personal threshold. Each individual of each tribe has a *Personal Threshold* that means the minimum percentage of her friends who must agree with her, not to change her decision. In another word, by changing the personal threshold, we will be able to change *bigotry* of individuals on their current decisions.

In this paper, we try to compare the isolated world with the aware world and analyze the effect of changes in *number of person's friends*, *personal threshold*, and *number of tribes* on the *rate of tribe's correct decision*. We look for a model which models human behavior in decisions made in a time period; therefore, we present a multigenerational model. Some of the main contributions of our model are as follows:

- In most previous models, initial decision for people was chosen randomly, while in our model the initial decision may be based on herd behavior [8]. This is a real assumption.
- We modify the Barabasi-Albert links formation model that shows the relations of friendship between people in real world, and use this modified version to modeling communications among tribes [4].
- As can be seen, everyone make decision based on the network structure, but her personality is important as well. We use this to examine the effect of different personality factor value on the percentage of the correct decision among the communities (tribes).

This paper is organized as follows: Section 2 describes the related work and provides the background of the problem.

Section 3 describes our multi-generational social learning model. Section 4 shows some real world example that our model can fit to them. Section 5 demonstrates theoretical aspect of the model. Section 6 presents the experimental result of game simulation. And finally, the paper concludes and our future directions to expand the model describe in section 7.

II. RELATED WORK

Herd behavior has been studied for many years in sociology, economy and network science. Anderson et al. [1, 2, 3] and Bikhchandani et al. [10] offered basic models for herd behavior. Devenow et al. briefly described examples of rational herding in financial markets [14]. Ting Lan examined the herding behavior in china market[18], Marco Cipriani et al. Estimate a Structural Model of herd Behavior in Financial Markets [19], and Glenn Davis et al. used applied data to investigate herd behavior [20].

As we said before, if people follow sequential decision model in their decision-making process, herd behavior can occur. Fiore et al. showed that how informational cascades can be avoided when people make decision only according to their private information [15]. Anderson and Holt showed that if people don't have enough information about their environment to make decisions, herd behavior would be the expected behavior [1, 2]. Classroom Game was the experiment that Anderson and Holt created to show this issue. We modify Classroom Game for our model. On the best of the authors' knowledge, this paper is the first one in presenting a social learning model for studying the effect of social ties in making the correct decision in human societies, based on analysing herd behavior.

III. OUR SOCIAL LEARNING MODEL

In this paper, we design a game with two phases. First, we simulate the modified classroom game for tribes with various populations in isolated world. Herding behavior may occur in each tribe. In our simulations, we assume the following facts:

- Isolated world includes of several tribes. Each tribe includes the nodes that each is a person who can make a decision.
- Populations of tribes grow with a number between 1 and 9, via nodes which are born according to power law [16].
- Each node has two choices: majority-blue and majority-red, and aware of the choice of other nodes in her tribe which were before her.
- For each person, the probability of observing blue marbles in majority-blue urn is 0.55 and in majority-red urn is 0.45.
- For each person, the probability of observing red marble in majority-red urn is 0.55 and in majority-blue urn is 0.45.
- Our world has S generations: each generation consists of nodes which are born in isolated world at a time and place in various tribes.
- We play the game for S generations, because in fact the populations of various tribes are growing with special rates.

Researcher showed that the fraction of cities with population k is roughly $1/k^c$ for some constant c [5, 6]. Because the populations of cities have been observed to follow a power law distribution, we identify the population growth of tribes in isolated world according to power law distribution.

We change the probabilities of the classic classroom game from $[1/3, 2/3]$ to$[0.45,0.55]$. Already Drehmann et al. also changed the probabilities of classroom game for their modified game [21]. By doing this modification, it's hard to make the correct decision, because in fact, the border between correct decision and wrong decision is not being clear, often.

Our isolated world, randomly being in majority-blue or majority-red situation, with the probability of $1/2$. Our game is run separately for n tribes. The nodes of each tribe respectively decide and declare their votes. The vote of each node is identified by calculating the probability of correct decision based on Bayesian rule [3]. Then, the vote of each tribe is determined by the majority of the votes. This process is run for all of the generations with the same urn. Finally, at the end of each generation, we analyse the correctness of decision of tribes in isolated world.

Then, we change the situation and make it possible to contact and interchanging information between each person of a tribe with other persons in another tribes. In order to create this opportunity, we established a link between two people from two different tribes. In our simulation we use these assumptions:

- Links generate based on the Barabasi–Albert model.
- Each node is aware of the vote of her neighbor's tribe.
- Each node has a personal threshold named *alpha.*

When each node in isolated world informed about her tribe's vote (include the vote of all nodes in previous generations, and nodes that were born before her), she makes her decision based on these information and her observation. Then, the game gives the permission of creating link for all nodes in world. By doing this, *the isolated world changes to aware world*.

By this change of situation, which occurs in the end of each generation, every nodes of that generation get the chance of changing their vote. Notice that, changing the vote for each node depends on her observation, her personal threshold, number of her neighbours and their tribe's vote.

IV. EXAMPLES IN REAL WORLD

Here, we give some examples of real world that correspond well with our model. First, suppose you want to eat out. In your way, you find two restaurants that are near each other. You don't have any information about how these restaurants served their delicious foods! If service is more important than expectation time for you, probably you will choose the most crowded one. Because crowded restaurants usually have better services [13]. This is *herd behavior*. If the restaurant owner which has fewer customers wants to attract more people, there are two factors which she can change them: *number of customer's friends* and *customer's personal threshold* (α). This is a fact that she can't change the number of customers' friends, but she can change customers' personal threshold by improving the quality of service, changing design, or gives a gift to some of customers.

Second, suppose a society is limited to the use of a specific technology (limitations such as filtering, censorship, or sanctions). For some reasons, such as benefits, cost, security and unawareness, using this limited technology becomes difficult. As we said before, there are two factors that give a person the chance of using technology: number of person's friends and her personal threshold. In this case, changing the number of person's friends is effective, e.g. crossing the filter by VPN, and removing sanctions are factors which change the number of person's friends. Now, by changing condition of society, if a person's awareness and information about limited technology increases, then chance of using limited technology by her will be increased. Our model is good to analyse such societies, and understanding the importance of freedom on embracing new technologies.

V. THEORETICAL CONCEPTS

In this section, we discuss about theoretical aspects behind our network game model of herding behavior.

a) Nodes Voting System

I. Isolated World

In the isolated world, people make decisions according to sequential decision model. Like other works in studying herd behavior, we use Bayesian rule to calculate probabilities [1].

$$Pr(A|B) = \frac{Pr(A)\, \Pr(B|A)}{\Pr(B)} \quad (1)$$

- Prior probabilities:

$$Pr(MR) = \frac{1}{2} \quad , \quad Pr(MB) = \frac{1}{2} \quad (2)$$

- Other probabilities:

$$Pr(R|MB) = 0.45 \quad , \quad Pr(B|MB) = 0.55 \quad (3)$$

In our game, each node tries to predict the conditional probability that the urn is majority-blue, given what she has seen and heard from the game.

$$p = \Pr[majority\_blue | what\ she\ has\ seen\ \&\ heard] \quad (4)$$

- $if\ P > \frac{1}{2}\ then\ she\ votes$ majority − blue (MB)
- $if\ P < \frac{1}{2}\ then\ she\ votes$ majority − red (MR)
- $if\ P = \frac{1}{2}\ then\ she\ votes\ what\ she\ has\ seen$

II. Aware World

In the aware world, each node is able to communicate with nodes in other tribes. Here we have:

- n: number of neighbours
- v: vote
- S_v: set of possible values for vote. $S_v = \{-1,1\}$
- a_i: vote of tribe of i^{th} neighbour
- S_{a_i}: set of possible values for vote of neighbour's tribes. $S_{a_i} = \{-1,0,1\}$

If vote is *blue*, then $v = 1$, and if vote is *red* then $v = -1$. Also, if the vote of tribe of i^{th} neighbour is *blue*, then $a_i = 1$; if the vote of tribe of i^{th} neighbour is *red*, then $a_i = -1$; and finally, If the vote of tribe of i^{th} neighbour is *abstained*, then $a_i = 0$.

There are two states that a node says what she has seen as her vote:

State1: *When the number of neighbours that their tribe's vote is same as what the target node has seen, divided by total number of target node's neighbours is equal more than α percent.*

Number of neighbours that their tribe's vote is same as what the target node has seen can be formulated as in (5).

$$f = \left|\sum_{i=1}^{n} \frac{a_i(v+a_i)}{2}\right| \quad (5)$$

So, in this case, the probability that a node state her vote same as what she has seen is:

$$\mathrm{P}(v) = \left(\frac{f}{n} - \frac{\alpha}{100}\right) \quad (6)$$

If $P(v) > 0$ current node declares what she has seen as her vote.

State 2: *While the first state is not established ($P\ (v) < 0$), or in another word while f/n ratio is less than α percent*

In this case, we use those neighbours who their tribe's vote is different from what current node has seen. The number of these neighbours are $\mathrm{n} - \mathrm{f}$; these neighbours include those either their tribe's vote is opposite of what current node has seen, or those their tribe's vote is abstained.

Now if the number of those neighbours which their tribe's vote is opposite of what current node has seen divided by $n - f$ is less than ½, current node declares what she has seen as her vote. (Notice that if current node had seen red/blue, opposite vote is blue/red for her; so abstained vote is not included in opposite vote.)

Formula (7) specifies number of neighbours which their vote is opposite of what current node has seen:

$$f' = \left|\sum_{i=1}^{n} \frac{a_i(v-a_i)}{2}\right| \quad (7)$$

The ratio in state 2 is shown in (8).

$$\frac{f'}{n-f} \quad (8)$$

So probability of that current node declares what she has seen as her vote is shown in (9).

$$G(v) = \frac{1}{2} - \frac{f'}{n-f} \quad (9)$$

If $G(v) > 0$, current node declares what she has seen as her vote.

If first state and second state both were not established, current node declares her vote opposite of what she has seen.

State 3*: when current node declares her vote opposite of what she has seen*.

So if formula (10) is established, current node will declare her vote opposite of what she has seen.

$$\begin{cases} P(v) < 0 \\ G(v) < 0 \end{cases} \quad (10)$$

In fact if the number of those neighbours which their tribe vote is opposite of what current node has seen divided by $n - f$ become equal more than ½ , current node will declares her vote opposite of what she has seen.

$$\begin{cases} P(v) < 0 \\ G(v) < 0 \Rightarrow \frac{1}{2} - \frac{f'}{n-f} < 0 \Rightarrow \frac{1}{2} < \frac{f'}{n-f} \end{cases} \quad (11)$$

Here, $n - f$ is the number of neighbours which their tribe vote is *different* from what current node has seen, and f' is the number of neighbours which their tribe vote is *opposite* of what current node has seen.

Finally, formula (12) specifies nodes voting system.

$$H = P + G + sign(P)(P - G) \quad (12)$$

If $H > 0$ current node declares what she has seen as her vote, and if $H < 0$ current node declares a vote unlike her observation. All we say is summarized in Table I:

TABLE I
NODES VOTING SYSTEM

$P(v)$	$+$	$+$	$-$	$-$
$G(v)$	$+$	$-$	$+$	$-$
$H(v)$	$+$	$+$	$+$	$-$
vote	observation	observation	Observation	~observation

b) Tribes voting system

To determine the vote of a tribe, we count number of blue and red votes separately, and then compare them with each other. We set vote of the tribe, the majority of color that its nodes declare as their vote. If the number of blue votes and red votes are equal, then we set vote of the tribe to abstained. Here we have:

- m: Number of members (nodes)
- v_i: Vote of i^{th} node
- S_{v_i}: Set of possible values for votes. $S_{v_i} = \{-1,1\}$

If vote of i^{th} node is blue then $v_i = 1$; if vote of i^{th} node is red then $v_i = -1$.

Number of blue votes can be formulated as in (13).

$$blue\ votes = \sum_{i=1}^{m} \frac{1+v_i}{2} \qquad (13)$$

And number of red votes formulated as in (14).

$$red\ votes = \sum_{i=1}^{m} \frac{1-v_i}{2} \qquad (14)$$

So, the tribe's voting system is such that:

- if (13) > (14), then vote of tribe will be blue,
- if (13) < (14), then vote of tribe will be red,
- if (13) = (14), then vote of tribe will be abstained.

c) Rate of correct decision in the world:

We determine rate of correct decision in the world as shown in (15).

$$R = \frac{W}{number\ of\ all\ tribes} \times 100 \qquad (15)$$

W: Number of tribes which their votes are similar to current urn color.

VI. Experimental Results[1]

Our social learning model have multiple factors such as number of neighbours and their votes, node's personal threshold, number of tribes and population of tribes. These factors have direct effect on the *rate of correct decision* of tribes. In this section, we analyse the simulated world based on different values of these factors.

First, we study the world in its isolated version and investigated the occurrence of herd behavior. Then, we study the aware world, which nodes able to link to each other freely.

I. Isolated world:

As we have shown in Fig.1, in the isolated world the rate of correct decision always has an upward trend. But, the growth usually stops between 10th and 30th generation and it remains stable. The reason of this growth is that the correct decision has higher chance of being selected. The reason of stability of growth in correct decision is that herding behavior occurs after several generations. Hence, new generations can't change decision of the tribe. We simulate the isolated world when the number of tribes is 10, 20, 30, 40, and 50 in Fig.1.

Our results have shown that correct decision in primary generation in the world has a minimum rate at about 45 percent. The chance that herding behavior occurs in the isolated world by classic classroom game is 80 percent [3]. On the other hand, for every herding game, there is a rate which cause people have wrong decision. In our game, the rate is the same for all the tribes in the world. Therefore, the chance of occurring herd behavior cause that the tribes can't improve the rate of correct decision and the diagram is almost the same for different number of tribes.

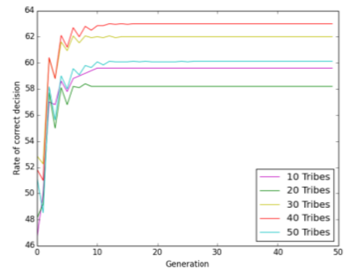

Figure 1. Herding behavior for different tribes.

II. Aware World

The rate of correct decision always has an upward trend in aware world, as well. This growth stops and remains stable at the best possible rate (i.e. 100) in the initial generation. In here, the generation and the values which the world remains stable at them, depend on the number of Barabasi–Albert links and the number of tribes in world.

In this simulation, as a result of the influence of α, the maximum rate of correct decision in tribes becomes about 100 percent. We show this in Fig.2 to Fig.5. When α is equal to 0, means that each person declare her observation as her decision. In here, although, the rate of correct decision constantly fluctuates, it has an upward trend without staying stable, as shown in Fig.6.

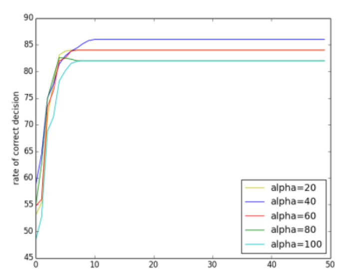

Figure 2. Diagram of 20 tribes with at least 3 links

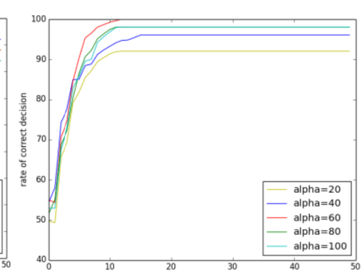

Figure 3. Diagram of 20 tribes with at least 5 links

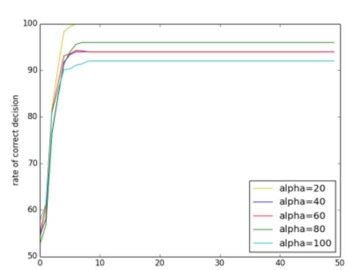

Figure 4. Diagram of 50 tribes with at least 3 links

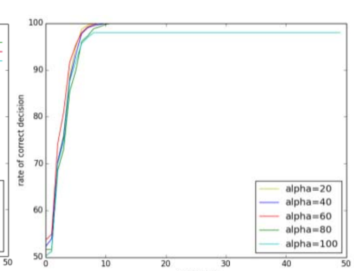

Figure 5. Diagram of 50 tribes with at least 5 links

[1] To increase accuracy of the results, all of the experiment averaged for 50 times.

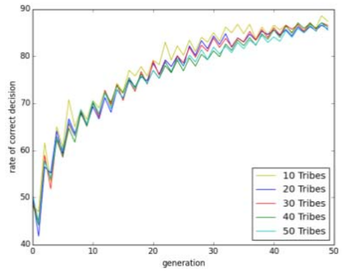

Figure 6. Diagram of different tribes with at least 3 links and $\alpha = 0$

By looking at the above diagrams and trying to compare them to each other, you can find an interesting result. In case of comparing isolated world diagrams with aware world diagrams when α is equal to zero, you can see that the rate of correct decision in the aware world will be better than in isolated world. Herd behavior is a rational behavior that cause to welfare loss, but we see here that if a person focus only on what she has seen, the rate of correct decision will be better in the world, as shown in Fig.7.

Also, if the number of links increases in the aware world, then the rate of correct decision will be improve (Fig.8). When the number of tribes in our simulation is increased to more than twenty tribes, then rate of correct decision in aware world will be better than that in isolated world.

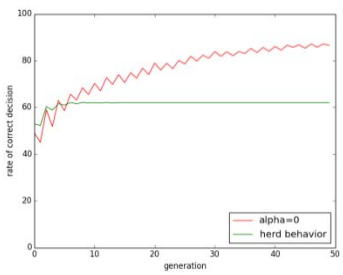

Figure7. Compare herd behavior with α=0

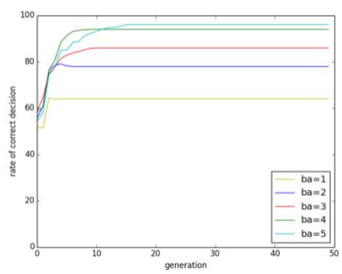

Figure 8. Variable link number in the aware world

VII. Conclusion and Future Works

In this paper we present a social learning model for studying herd behavior based on sequential decision model in isolated world, and then with a change in situation, the world is led to become an aware world. In aware world, people may change their decision according to several factors. The two most important factors are the number of person's friends and their personal threshold. We analyse rate of correct decision in the world along this process.

We showed that the rate of tribes' correct decision in an aware world is more than the rate of tribes' correct decision in an isolated world. Increasing number of person's friends, improves the rate of tribes' correct decision. Changing personal threshold (bigotry), changes the rate of tribes' correct decision about at most 10 percent. Furthermore, increasing number of tribes in aware world, improve the rate of tribes' correct decision. Finally, we see that if people make a decision based on what they have seen, rather than what the herd is doing, the rate of correct decision is much more.

In the future works, we can focus on three parts of our model: the network game that presents decision-making factors, network structure and theoretical part of the model.

We can change the game by increasing number of choices, changing decision model, design a model which have punishment for those who are disagree with their tribe. We can change decision-making factors by involving decision of our tribe and our own previous decision, or we can change importance of some tribes by setting some priority.

We can change the network structure by not giving freedom to all generations, each tribe just have permission to communicate with certain tribes and considering migration concept between tribes. In theoretical part we can consider finding minimum number of friendly links for each person in order to maximize aggregate welfare, and also finding those tribes which communicate with them in order to maximize aggregate welfare of a tribe.

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