Model Structure of Agent-Based Artificial System for Reproducing Bullying Phenomenon

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ABSTRUCT.

The macrophenomenon associated with bullying is characterized by the emergence of bullies, the bullied, and a third party that makes up the majority, as well as persistent and offensive behavior by the perpetrator against the victim as particular agents. To elucidate the mechanism of bullying through agent-based modeling, this paper analyzes the structural aspects of the model that are considered indispensable in reproducing the bullying phenomenon by systematically changing the behavioral rules of the model. One of the necessary conditions for the model structure is found to be that each agent has the characteristic tendency of tuning and excluding behavior, which is modeled using shared values and an agent-specific threshold for the tuning and excluding actions. This model successfully reproduced the emergence of the third party, as well as the victim and perpetrator, during the process of the agents' actions and interactions. However, this model could not reproduce the emergence of the tendency for intensively repeated attacks by specific perpetrators against specific victims. Through the analysis of various factors, it is concluded that people who are less likely to tune with others are more likely to become solo and not belong to any groups, which increases the likelihood of being a victim of bullying. The personality conditions for becoming the perpetrator could not be entirely determined by the simple behavioral rules employed in this study, suggesting that the inclusion of motivation-related viewpoints could be required. Based on these results, the mechanisms and countermeasures for bullying are discussed.

ACM Reference format:

Shigeaki Ogibayashi and Kazuya Shinagawa. Model Structure of Agent-Based Artificial System [SBJ1] for Reproducing Bullying Phenomenon. 8 pages.

Keywords

Agent-based modeling, Bullying, Model structure, Shared value, Tuning and exclusion behavior, Mechanism, Countermeasure

1 INTRODUCTION

Although bullying is a crucial social phenomenon, no effective countermeasures have yet been established. One reason seems to be that the underlying mechanism for bullying behavior is not well understood. There are many previous studies related to bullying [1]–[12]. Many studies have focused on the cause of bullying. Some argue that the perpetrator is the origin of the bullying, and his or her envy and self-esteem are the factors responsible for bullying [1][3]. Others believe that the personality of the victim is the cause of bullying. Zapf [3] classified the causes of bullying into three categories, namely the victim, the perpetrator, and the organization and pointed out that bullying can be caused by more than one factor simultaneously; therefore, one-sided explanations should be avoided. He also identified that research into the causes of bullying is insufficient, mainly because many reports are based on interviews with victims while the perspectives of perpetrators and potential bystanders are not considered. Because of the limitations of conventional approaches, there is clearly a limit to how well the dynamic characteristics of the occurrence of bullying can be elucidated.

However, it should be noted that agent-based modeling (ABM) is an effective approach for studying the mechanisms behind dynamic characteristics of social phenomena. Although various features of ABM have been described in the literature [13], the most essential feature of ABM is that it is a bottom-up modeling method in the sense that the artificial society modeled on a computer works, in principle, under the same mechanisms as in the real system. According to one of the authors' previous studies on ABM applied to the macroeconomic system [15][16][17], there exists a specific system structure of the model that is indispensable in reproducing the desired macrophenomenon. In other words, the categories of agents and their behavioral rules, including their attribute variables, are required to be similar to those of the real system for the model to reproduce the emergence of the desired macrophenomenon. If this requirement is not fulfilled, the ABM cannot reproduce the phenomenon, even at a qualitative level. We believe the system structure that is indispensable in reproducing a phenomenon can be elucidated by a series of computer experiments in which factors are systematically changed one by one while other factors remain constant. Moreover, by elucidating the indispensable model structure, we can obtain a greater understanding of the causal mechanism behind the macrophenomenon.

The macrophenomenon associated with bullying is characterized by two features. First, the emergence of bullies, the bullied, and a third party, which makes up the majority. Second, persistent and repeated attacks conducted by a specific person or group, as the perpetrator, against a particular person or group as the victim. Some researchers have used ABM to study the bullying phenomenon. For instance, Maeda et al. [14] developed an ABM that models the tuning and excluding actions of agents and tried to reproduce the emergence of the bullied. However, few studies have attempted to elucidate the indispensable system structure of the model required to reproduce the phenomenon.

Using the ABM approach, this study analyzes the factors within the model structure that are indispensable in reproducing the characteristic features of the bullying phenomenon. This allows for a discussion on effective measures for preventing the bullying phenomenon from occurring. The model in the present study is based on the behavioral rules proposed by Maeda et al. [14]. Additional factors relating to the model structure are introduced as experimental levels to clarify which conditions are indispensable and which are not for reproducing the bullying phenomenon.

2 METHOD OF STUDY

2.1 Model

The artificial system includes n agents. Each agent has a value vector of size M, each element of which is assigned a value of 1 or 0. This vector represents a set of values with M elements, each of which corresponds to traits in the real world covering preferences, skills, and behavioral patterns, and the value of 1 or 0 signifies whether or not that trait is selected or owned by the agent. The value of the k[th] element of the i[th] agent is represented by $v_{i,k}$. The total number of selected values for the i[th] agent is given by Equation (1), which is assumed to range between the upper and lower limit $m_{\max}$, $m_{\min}$.

$$m_i = \sum_{k=1}^{M} v_{i,k}$$
$$where,\ v_{i,k} = 1\ (when\ selected) \qquad (1)$$
$$= 0\ (when\ not\ selected)$$

The agent who performs the action and the agent who is the object of the action are denoted by the subscripts *act* and *obj*. Shared and non-shared values are defined as those in which both $v_{act,k}$, $v_{obj,k}$ are 1 or one of the values is 0, respectively.

Each agent communicates through tuning actions, excluding actions, or doing nothing depending on the action probability given by Equation (2), in which the numerator represents the shared value given by Equation (3). It is assumed that each agent has characteristic threshold values for tuning and excluding actions, and these are defined as uniform random numbers in the range [0, 1].

$$p(act, obj) = c(act, obj) / m_{act} \qquad (2)$$

$$c(act, obj) = \sum_{k=1}^{M} v_{act,k} . v_{obj,k} \qquad (3)$$

In the calculation, a pair consisting of an active agent and an objective agent is selected at random, and the active agent performs one of three actions on the objective agent. This will be either a tuning action, excluding action, or doing nothing. Repeating this process for all of the agents makes up one step of the calculation. During the repeated steps, the pattern of the selected values of each agent may change. As a result, the number of selected values may increase in some agents through the tuning action, which increases the number of shared values with respect to others. Thus, a group of agents emerges in which the members have the same set of values. In contrast, excluding actions will decrease the number of selected values in some agents, leading to solo agents who do not share any value with other agents.

In this model, an agent who excludes others most frequently without being excluded often corresponds to the bully or perpetrator, an agent who is frequently excluded without excluding others corresponds to the bullied or victim, and the other agents who exclude others as well as being excluded less frequently correspond to the third parties or bystanders.
In a typical experiment, the tuning and excluding actions are defined as follows.

2.1.1 Tuning Action

The active agent conducts the tuning action defined below when the action probability exceeds the tuning action threshold, as stated by Equation (4). The tuning action threshold is a random number in [0, 1] and is fixed for each agent.

$$p(act,\ obj) > g_{act}$$
$$where\ \ g_{act} : agent's\ threshold\ of\ tuning\ action \qquad (4)$$

The active agent randomly selects one of the k values characterized as $v_{act,k} = 0, v_{obj,k} = 1$, and changes its own value to $v_{act,k} = 1$. However, when m_{act} exceeds the upper limit $m_{\max}$ under this procedure, the active agent additionally selects another value p at random from the set of values characterized as $v_{act,p} = 1, v_{obj,p} = 0$ and changes the value to $v_{act,p} = 0$. Thus, the tuning action modifies the active agent's set of selected values to make it closer to that of the objective agent.

For comparison, the case in which g_{act} is not inherent to each agent but given by the same uniform random number in the range [0, 1], which is computed at each step, is also calculated (see EC3 and EC2 in Table 1).

2.1.2 Excluding Action

The active agent conducts the excluding action defined below when the conditions given by Equation (5) are fulfilled. The excluding action threshold is assumed to be given by a random number in [0, 1] and is fixed for each agent.

$$\begin{aligned} &p(act, obj) < e_{act} \;\; and \;\; m_{act} > m_{obj} \\ &where \; e_{act} : agent's \; threshold \; of \; excluding \; action \end{aligned} \tag{5}$$

When m_{obj} is greater than the lower limit $m_{\min}$, the active agent selects one of the values p at random from the set of values characterized by $v_{act,k} = 1, v_{obj,k} = 1$, and changes the value of the objective agent to $v_{obj,p} = 0$. Thus, the excluding action modifies the set of selected values in the objective agent to make it more different from that of the active agent (see EC6 and EC5 in Table 1).

For comparison, the case in which the excluding action is only conducted when $m_{act} > m_{obj}$ (see Equation (6)) is also calculated (see EC4 and EC3 in Table 1). Additionally, the case in which the exclusion action is only conducted when the difference in the number of shared values between the current and previous steps exceeds some threshold value is considered. In this study, the threshold is assumed to be 1, as stated in Equation (7) (see EC2 in Table 1). Equation (7) is the assumption made by Maeda et al. [11].

$$m_{act} > m_{obj} \tag{6}$$

$$\begin{aligned} &c'(act, obj) - c(act, obj) > 1 \\ &where \; c(act, obj) : Number \; of \; shared \; values \; in \; the \; current \; step \\ &\qquad c'(act, obj) : Number \; of \; shared \; values \; in \; the \; previous \; step \end{aligned} \tag{7}$$

2.1.3 Reaction Against Excluding Action

For comparison with the base model, the effect of the reaction against an excluding action is analyzed in which a characteristic random number in [0, 1] is assigned to each agent. Depending on this number, an agent that has just been subjected to an excluding action performs one of the three choices, namely an excluding action, a tuning action, or doing nothing toward the objective agent [SBJ2] . This action is conducted in addition to the abovementioned shared-value-dependent tuning or excluding actions (see EC5 in Table 1).

2.2 Experimental Conditions.

The behavioral rules and parameter values are presented in Table 1. The base model is EC5, which includes agent-specific tuning and excluding actions. The models denoted EC1–EC4 and EC6 represent the modified versions for comparison with the base model in which the behavioral rules are changed. The aim of the comparison is to elucidate the effect of the model structure on the emergence of the bullying phenomenon and to understand the conditions required to reproduce this phenomenon.

Table 1. Calculation conditions

		Model with agent-specific rules			Model without agent-specific rules		
		Model with agent's threshold of tuning and exclusion, and the reaction against exclusion	Model with agent's threshold of tuining and exclusion, (The base model)	Model with agent's threshold of tuning only	Model with revised rule of exclusion	Model presented by Maeda	Model with tuning only
Name of experimental conditio		EC6	EC5	EC4	EC3	EC2	EC1
Behavioral rules of agent	Tuning	p(act,obj)>g_{act}	p(act,obj)>g_{act}	p(act,obj)>g_{act}	p(act,obj)> δ	p(act,obj)> δ	p(act,obj)> δ
	Exclusion	p(act,obj)<$e_{act,}$ m(act)m(obj)	p(act,obj)<$e_{act,}$ m(act)m(obj)	m(act)>m(obj)	m(act)>m(obj)	c(act,obj)$^{t-1}$-c(act,obj)^{t}>1	–
	Reaction against exclusion	Tuning, exclusion, neutral, depending on the agent	–	–	–	–	–
Experimental parameters	Number of agents	30	20				
	Number of values	100	50				
	initial number of selected values	10	10				
	Max. number of selected values	15	15				
	Min. number of selected values	5	5				
	Max. number of steps	1000000	1000000				
	Number of runs	10	10				

Note: g_{act}:The threshold value for tuning action of the agent, defined by a [0-1] random number.
e_{act}: The threshold value for exclusion action of the agent, defined by a [0-1] random number.
δ : A [0-1] random number

3 SIMULATION RESULTS

The simulation results for each of the six experimental conditions are described in this section. In Figs. 2–9, we use the notation 'solo,' 'Mxx,' 'Mxx_1,' and 'Mxx_2,' where solo refers to an agent who is not a member of any groups and Mxx refers to an agent who is a member of a group with xx members. The notation Mxx_1 and Mxx_2 is used when more than one group have the same number of members.

3.1 Results without agent-specific rules

3.1.1 Model with tuning only (EC1)

Although the initial set of values is randomly assigned to each agent, the set becomes the same for all agents in the equilibrium state, as shown in Fig. 1. This result agrees with the findings reported by Maeda et al. [14], indicating that no conflict between bullies and the bullied emerges with this model.

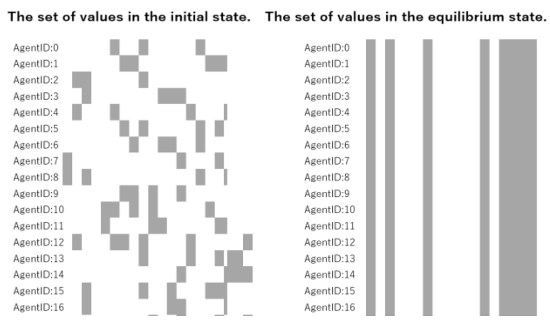

Fig. 1. Example of the set of values in the initial and equilibrium states obtained in the model with tuning only.

3.1.2 Model with tuning and excluding actions, where the exclusion rule presented in the literature is employed (EC2)

This is the case in which the rule of exclusion employed by Maeda et al. [14] is assumed. In this case, two types of agent emerge as a result of the interaction among agents as shown in Fig. 2. Those are solo agents, whose set of selected values is not coincident with that of others, and agents in a group, where the set of selected values is coincident inside the group. However, when looking at the relationship between the number of excluding actions and the number of times the same agent is excluded, it is evident in Fig. 2

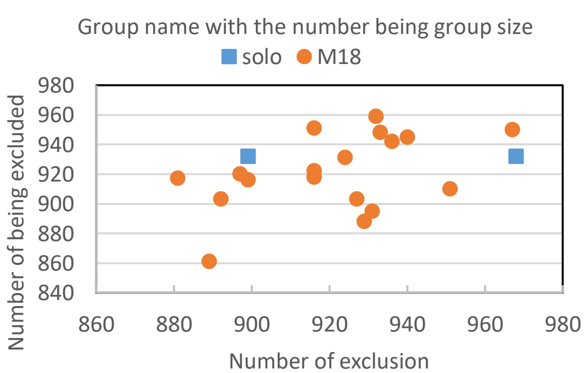

Fig. 2. Example of the relationship between the number of excluding others[SBJ3] and the number of times an agent is excluded by others in model EC2.

that agents who exclude other agents more often are more likely to be excluded by other agents.
Thus, it is concluded that bullies and the bullied do not emerge as conflicting agents under the conditions of this model.

3.1.3 Model with tuning and excluding actions, where the new exclusion rule is employed (EC3)

When the exclusion rule is changed from that assumed in Equation (7) to that assumed in Equation (6), a negative correlation emerges between the number of exclusions performed by an agent and the number of times that agent is itself excluded, as shown in Fig. 3. This result indicates the separate emergence of agents who are more likely to exclude others than to be excluded and agents who are more often excluded by others. The former are typical candidates for the perpetrator, whereas the latter are candidates for the victim. Thus, bullies and the bullied emerge under the conditions of this model.

However, it should be noted that we cannot observe any agents who rarely exclude others and are rarely excluded by others, indicating that third-party agents who are not directly involved in the conflict between the perpetrator and the victim do not emerge with this model.

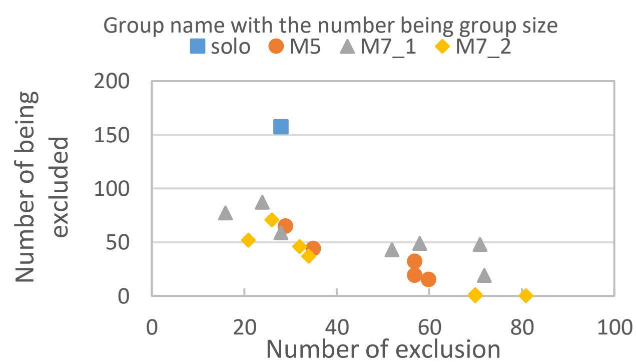

Fig. 3. Example of the relationship between the number of exclusions and the number of times an agent is excluded in model EC3.

3.2 Result with agent-specific rules

3.2.1 Model with agent's tuning threshold only (EC4)

When the threshold value for the tuning action is defined as being specific to each agent, the negative relationship between the number of exclusions and the number of times the same agent is excluded emerges, as shown in Fig. 4, even though the criteria for the excluding action is randomly defined. Moreover, agents in the same group exhibit a similar number of exclusions as other agents, as seen in Fig. 4, indicating that they behave similarly. In addition, agents whose threshold value for tuning is very large are more often excluded by others, as shown in Fig. 5, suggesting that agents who are less likely to tune with others are more likely to become victims. However, as is evident from Fig. 4, the third-party behavior does not emerge with this model.

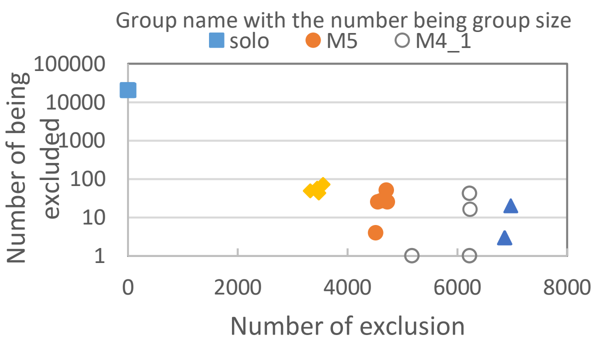

Fig. 4. Example of the relationship between the number of exclusions and the number of times an agent is excluded in model EC4.

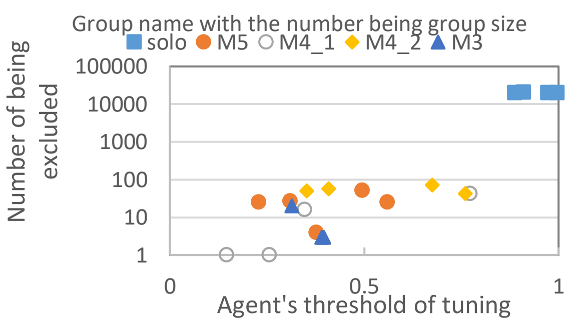

Fig. 5. Effect of the agent's tuning threshold on the number of cases of being excluded in model EC4.

3.2.2 Model with agent's threshold of tuning and exclusion (EC5, the base model in the present study)

An example of the relationship between the number of exclusions and the number of times an agent is excluded is shown in Fig. 6. Note that the agents in Fig. 6 are categorized into three types. The first type consists of agents who are very often excluded but rarely exclude others: these are the victims and the candidates for victims. The second type includes agents who are likely to exclude others while rarely being excluded themselves: these are the perpetrators and the surrounding agents. The remaining group of agents, for which the number of exclusions and the cases of being excluded are relatively low, corresponds to the third party. The typical victim in Fig. 6 is the agent who is most often subjected to excluding actions. In this case, this is agent 16, who was excluded 38 times (see the vertical axis in Fig. 6). Fig. 7 shows the perpetrators of these excluding actions and the number of times they applied this action to agent 16. Note that the agent who excluded others the most often, agent 5 in this case, applied the most excluding actions to agent 16. This indicates that agent 5 is the main perpetrator toward the victim agent. Thus, we can conclude that one of the features of the bullying phenomenon, namely the existence of the third party as well as the victim and the perpetrator, is successfully reproduced with this model.

Moreover, as can be seen in Fig. 6, the third-party agents emerged are categorized into three types, namely, agents whose number of exclusion and the number of times of being excluded are both very small, the agents whose number of exclusion is very close to that of the perpetrator, and the agent whose number of times of being excluded is very close to that of the victim. These are the bystanders, the reinforcers of bullies, and the defenders of the victim, respectively, which are well coincident with that pointed out in the literature [8].

However, although the main perpetrator stated above is a member of a group with nine members, having the same set of shared values, as seen in Fig. 6 and Fig. 7., there are agents in this group who only exclude the victim agent once or twice, namely they behave differently. This indicates that this model does not reproduce another feature of the bullying phenomenon, namely the tendency for the perpetrator as a specific agent or group to attack the victim as a particular agent persistently and repeatedly.

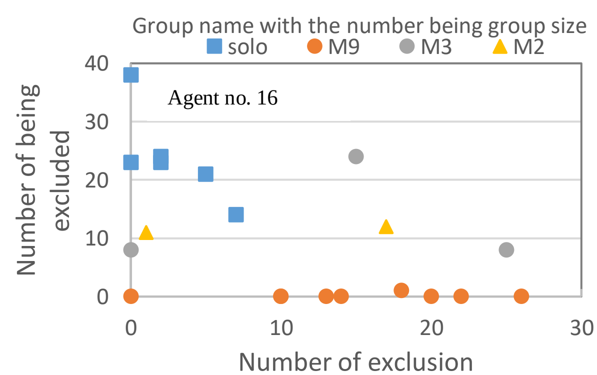

Fig. 6. Example of the relationship between the number of exclusions and the number of times an agent is excluded in model EC5.

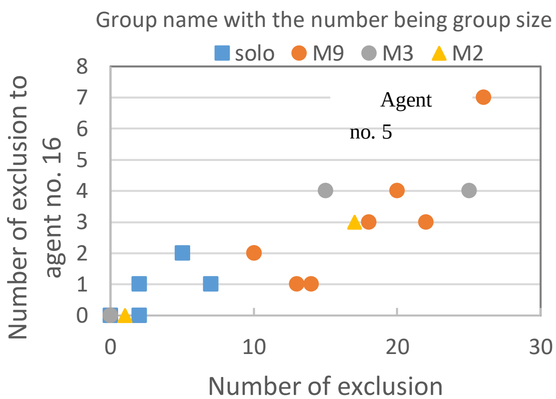

Fig. 7. Number of excluding actions applied to agent 16 in relation to the total number of exclusions.

The effects of the threshold values for tuning and excluding actions on the number of times agents are excluded are shown in Figs. 8 and 9. These figures indicate that the number of times an agent is excluded by other agents is mainly dependent on the agent's tuning threshold, with the effect of that agent's exclusion threshold being relatively small. Moreover, as can be seen in Fig. 8, agents with lower tuning thresholds who are more likely to tune with others tend to become members of a large group and are rarely excluded. Agents with larger tuning thresholds are less likely to tune with others and tend to become solo agents, making them more likely to be excluded by others.

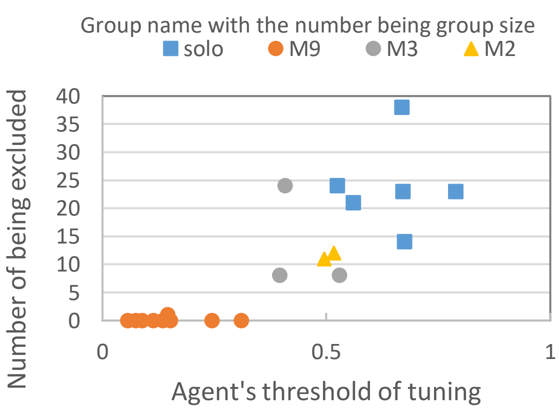

Fig. 8. Effect of the agent's tuning threshold on the number of times they are excluded by other agents.

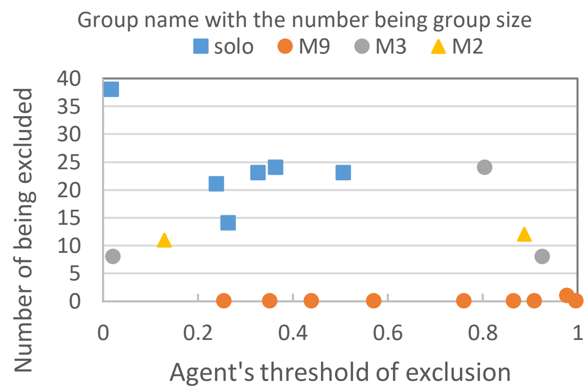

Fig. 9. Effect of the agent's excluding threshold on the number of times they are excluded by other agents.

3.2.3 Model with agent's retaliation against exclusion as well as tuning and excluding actions (EC6)

The effect of the reactive action against the excluding action is now analyzed. A characteristic random value in [0, 1] was used to express the type of retaliation performed by each agent. As a retaliation action, the agent selects one of three choices, namely, an excluding action, tuning action, or doing nothing, when the assigned random number is less than 0.34, greater than 0.67, or between these two values, respectively. The number of times each agent was excluded is shown in Fig. 10 as a function of the number of excluding actions and in Fig. 11 as a function of the agent's tuning threshold.

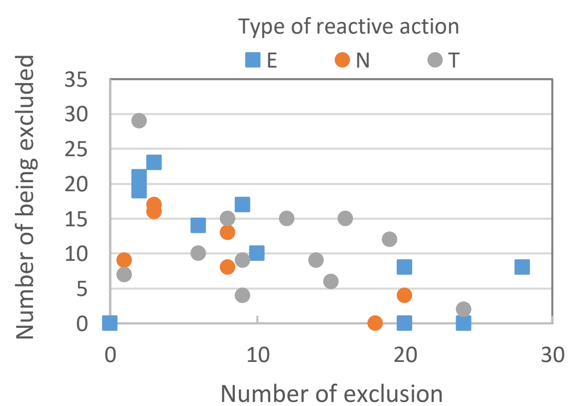

Fig. 10. Effect of reactive actions seen in the relationship between the numbers of exclusions and cases of being excluded in model EC6. Reaction types are denoted as E for exclusion, N for neutral (doing nothing), and T for tuning.

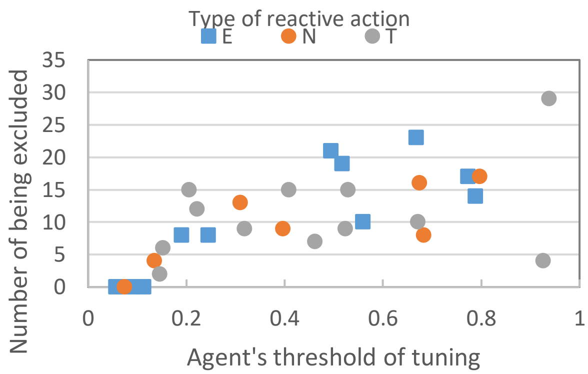

Fig. 11. Effect of the agent's tuning threshold and the reactive actions on the number of cases of being excluded in model EC6. Reaction types are denoted as E for exclusion, N for neutral (doing nothing), and T for tuning.

As evident in Figs. 10 and 11, the influence of the reactive actions is negligible. This indicates that persistent and intensive attacks by the perpetrator toward the victim cannot be explained by simple rules using the tuning and exclusion thresholds assumed in the present model. Other factors should be considered to model the agents' personality, which could be essential in determining the cause of bullying.

3.3 Summary of the simulated results

As is clear from the experimental results, the macrophenomenon that emerges in the artificial system strongly dependent on the system structure.

The existence of the third party, as well as the perpetrator and the victim, is only reproduced under the assumption that the likelihood of both the tuning and excluding actions is agent-specific, and the exclusion is conducted when the number of values held by the objective agent is lower than that of the active agent, as explained in the result of EC5. Without these conditions, the third party does not emerge in the artificial society

Moreover, in the model EC5, third-party agents emerged are categorized into three types, namely, bystanders, the reinforcers of bullies, and the defender of the victim. These categories of agents are well coincident with that pointed out in the literature [8].

The calculated results in the model EC5 also indicate that the number of times an agent is excluded by others is mainly dependent on the agent's tuning threshold, while the influence of agent's exclusion threshold is relatively small.

Another feature of bullying, namely that persistent and repeated attacks are conducted by a specific person or group toward another particular person or group, could not be reproduced within the framework of the present model, even when some form of retaliation or reaction was incorporated into the model.

The reasons, mechanisms, and countermeasures for bullying will be discussed in the next section.

4 DISCUSSION

The existence of the third party, as well as the perpetrator and the victim, is reproduced under the assumption that the likelihood of both the tuning and excluding actions is agent-specific, and the exclusion is conducted when the number of values held by the objective agent is lower than that of the active agent, as explained in the result of EC5. Without these conditions, the third party does not emerge in the artificial society.

Based on this result, the basic mechanism of bullying is considered as follows. The people in the organization have the tendency of tuning with others and that of excluding others as essential characteristics. Due to this tendency as well as the effect of the interaction among agents, the agent who is more likely to tune with others tends to become a member of a group with increasing the number of shared values, and is therefore less likely to be excluded by others, while the agent who is less likely to tune with others tends to become a solo agent with decreasing the number of shared value and therefore more likely to be excluded by others. Thus, the agent who is the typical case of the former tends to become a perpetrator and the typical case of the latter tends to become a victim, and others are the third-party agents consisting of bystanders, reinforcers of the bullies, and defenders of the bullied.

However, another feature of bullying, namely the persistent and repeated attacks conducted by a specific person or group focusing on the particular agent is not reproduced in the present model. This indicates some additional factors will be responsible for the emergence of this tendency. What could those factors be?

Based on the present study, such factors are considered to be something related to the motivation for the excluding actions. According to the literature [7],[13], such motivation for excluding others could come from the bullies pursuing high status in the peer hierarchy. To effectively gain the positive feedback from the peers such as smiling and laughing, bullies choose victims who are submissive, insecure about themselves, physically weak, and in a low-power, rejected position in the group. The factors mentioned above can be taken into account in the present model by assuming additional rules regarding the agents' behavior, which remains as a future subject.

From the result of the present study as well as above discussions, the following two countermeasures are considered effective. One is the intentional tuning behavior with the victim which could help him/her to become a member of a group, and therefore less likely to be excluded. Another one is the bystanders' reaction not to reinforce the bullies so that bullies cannot get positive feedback for their attacks toward the victim. To effectively promote these measures, the roll of organization would be also important.

5 CONCLUSIONS

The macrophenomenon associated with bullying is characterized by the emergence of bullies, the bullied, and third-party bystanders, which are the majority. Another characteristic is the persistent and offensive behavior by the perpetrator against a specific person. To elucidate the mechanism of bullying by agent-based modeling, this paper analyzed the structure of ABM, which is considered indispensable in reproducing the phenomenon, by systematically changing the behavioral rules in the simulation. As a result, the following findings were obtained.

The emergence of the third party, as well as the victim and the perpetrator, is reproduced under the assumption that each agent has the characteristic tendency of tuning and excluding behavior that is modeled according to shared values with others, and that exclusion is conducted when the number of values held by the objective agent is lower than that of the active agent.

Based on this result, the basic mechanism of bullying is considered that due to the agent-specific tendency of tuning and exclusion actions as well as the interaction among them, the agent who is more likely to tune with others tend to become a member of a group with increasing the shared values, while the agent who is less likely to tune with others tends to become a solo agent with decreasing the shared values and therefore more likely to be excluded by others. Thus, the agent who is the typical case of the former tends to become a perpetrator and the typical case of the latter tends to become a victim, and others are the third-party agents consisting of bystanders, reinforcers of the bullies, and defenders of the bullied.

Despite the success in generating the emergence of the third party, this model could not reproduce the emergence of the tendency for intensively repeated attacks by specific perpetrators against specific victims. This remains a subject for future study.

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Appendix: Overview, Design concepts, Details Protocol

This appendix describes the model in terms of the Overview, Design concepts, and Details(ODD) protocol by Grim, et al.(2006). Grim, et al. (2006).

1. Purpose

The purpose of this model is to elucidate the model structures which is indispensable in reproducing the emergence of bullying phenomena, thereby elucidating the underlying mechanism of bullying. This model also aims to provide an example of the evidence that there exists a set of structural factors that are indispensable in reproducing the macrophenomenon in the agent-based model in which only the categories of agents and their behavioral rules without any assumption regarding the relationship between aggregate variables.
In the present study, the features associated to bullying are assumed to consist of two; first the emergence of the third-party agents as well as the perpetrator and the victim, second the emergence of persistent and repeated attacks conducted by the perpetrator toward the victim as particular agents.

2. Entities, state variables, and scales

The entities included in this model are agents such as students and working individuals who consist of the organization or a social system in which bullying takes place. The categories of agents relating to the hierarchy in the organization, such as the teacher in school and various types of the manager in the firm are not taken into account in the present model.

State variables consists of the followings.
(1) State variables of each agent, the numerical value of which varies during the time steps.

a) Each element of the value vector of size M, which is assigned a value of 1 or 0. This vector represents a set of values with M elements, each of which corresponds to traits in the real world covering preferences, skills, and behavioral patterns, and the value of 1 or 0 signifies whether or not that trait is selected or owned by the agent.
b) The number of times of being excluded by others
c) The number of times of excluding others.
d) Shared values with other agents
e) Total number of the selected values in the value vector.

(2) State variables of each agent, the numerical value of which does not vary during the time steps.

a) Threshold value for tuning action
b) Threshold value for excluding action

Variables relating to scales are the following.

a) The number of agents included in the system
b) The size of the value vector
c) The minimum number of the selected values
d) The maximum number of the selected values.

3. Process overview and scheduling

In the calculation, a pair consisting of an active agent and an objective agent is selected at random, and the active agent performs one of three actions on the objective agent. This will be either a tuning action, excluding action, or doing nothing. Repeating this process for all of the agents makes up one step of the calculation. During the repeated steps, the pattern of the selected values of each agent may change. As a result, the number of selected values may increase in some agents through the tuning action, which increases the number of shared values with respect to others. Thus, a group of agents emerges in which the members have the same set of values. In contrast, excluding actions will decrease the number of selected values in some agents, leading to solo agents who do not share any value with other agents.

4. Design concepts

***Basic principles*:**

In the case of the agent-based model of entirely bottom-up type, namely, the model in which only the categories of agents and their behavioral rules are assumed without any assumptions relating to the relationship between aggregate variables, the behavior of an artificial social system can mimic the behavior of real world if the system structure of the model and that of real world are in the relationship of homomorphism. This relationship is considered fulfilled when the structural factors of the modeled systems that cause the emergence of the social phenomenon in question are essentially the same as those of real system. In other words, there exists a set of structural factors for each of the aggregate phenomenon in the social system which is indispensable for the model to reproduce the emergence of the phenomenon.

The structural factors of the system are the categories of agents included in the system, the behavioral rules of each category of agent and the attribute variables relating to the behavioral rules including state variables, which can be elucidated by a set of controlled experiments in which only one factor is varied one by one at a time with other factors being kept constant. Through this experimental procedure, we can elucidate what factor is indispensable in reproducing the phenomenon and what factor is not.

The structural factors thus elucidated are indispensable in reproducing the phenomenon because of the underlying causal mechanism of the phenomenon. Therefore, by considering the reason why these structural factors are indispensable in producing the phenomenon, we can come to understand the causal mechanism of the phenomenon.

With this principle, agent-based modeling can be a useful tool to elucidate the mechanism of the complex social phenomena. In agent-based modeling, it is significantly important to clarify the structural factors for each of the social phenomenon. We believe that piling up this kind of knowledge will provide us the future where each of the social problems that are mutually dependent and therefore incredibly complex can be systematically solved in an evidence-based manner.

Emergence:

The agents included in the modeled artificial systems should be designed as heterogeneous autonomous. Their behavioral rules might be similar for each of the categories of agents, but the numerical values of their state variables should be different. Then, as the heterogeneous agents differently behave and interact each other macroscopic phenomena emerge as a result of their actions and interactions, which in turn affects microscopic behavior of agents, resulting in a micro-macro link in the dynamics of the systems. Thus, the artificial economic systems can behave as complex systems.

In the case of the present model, the most important set of state variables of agents are the value of each element in the value vector and the number of shared value with each of the other agents. This set of state variables varies during the time steps due to the interaction with other agents, which affects the actions of itself in the next time step. Thus the mergence of bullying in the present model is a result of the micro-macro link in the dynamics of the system.

Adaptation:

Agent performs either tuning action, or excluding action, or doing nothing toward the objective agent, depending on the action probability defined as the ratio of the number of shared value with the objective agent to the total number of selected values of itself.

Here, tuning action is the type of action that modifies the set of selected values to make it closer to that of the objective agent, while excluding action is the type of action that modifies the set of selected values of the objective agent to make it more different from that of itself. the objective agent. Tuning actions increase the number of selected values in some agents, leading to the emergence of a group in which the members have the same set of values. On the other hands, excluding actions decrease the number of selected values leading to the emergence of solo agents who do not share any value with other agents.

Thus, through the tuning and excluding actions, agents adapt themselves to other agents.

Objectives:

Agents aim to adapt themselves to other agents through tuning and excluding actions. This results in the emergence of the perpetrator, the victim and the third-party agents which consists of the three categories of agents, namely, the reinforcers of bullies, the defender of the victim and the bystanders.

Prediction:

The present model predicts the emergence of bullying in which the following criterion is assumed for the translation of calculated results to the real phenomenon.

Bullying is assumed to be a set of excluding actions repeatedly conducted toward a specific person. The perpetrator is the agent in the model who excludes a specific agent the most, the victim is the agent who is excluded by a specific agent the most and the third party is the other agents consisting of the bystanders, reinforcers of the bullies, and the defenders of the victim.

Sensing.

Present model assumes that each agent recognizes other agent's value vector, thereby sensing the shared value with other agents as well as the other agent's total number of values

Interaction.

Agents mutually interact through tuning and excluding actions.

Stochasticity:

At the start of simulation, the numerical value of each element in the value vector is randomly assigned using normal random number in the range between [0,1]. In addition, the condition of performing tuning action is stochastically decided in the case of some experimental conditions, where it is assumed that the agent performs tuning action if the action probability is greater than the normal random number in [0,1].

Collectives:

Present model does not include any collectives such as organizations or firms.

Observation:

At the end of each time step, following variables are printed out for observation.

Those are, the number of times of excluding each of the other agents, the number of times the agent was excluded by each of the other agents, the numerical values in the value vector .

1.

5. Initialization

The agent in the present model has the value vector with M elements, each of which is initially assigned 1 or 0 at random. This assigned values for the value vector defines the initial state of the agents.

6. Input data

No data from the real system is used as input data for the simulation.

Only experimental parameters are given as input data which includes the number of agents, number of the elements in the value vector, initial number of selected values, maximum number of selected values, minimum number of selected values, maximum number of steps for the simulation and the number of runs for repeating the simulation with different random numbers.

7. Submodels

No submodels are included in the present model.