Generation of Relations between Individuals based on a Stochastic Automaton and an Analogy from Social Psychology

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Abstract

We regard internal states of an automaton as emotional states of an individual, its outputs as its actions towards another individual, and a parameter affecting its state transition as a personal trait. We therefore propose a representation of an individual with emotional states and a certain personality, by a stochastic automaton and a model of a group in which each individual begins conversations with another individual. The relations between individuals are generated from results of the conversations based on the congruity theory in social psychology.

1 Introduction

Since the 1960s, many studies on computational models for emotion have been proposed[1][5]. The purpose has been to represent the emotional process in one individual, blackboard models, production systems, neural networks, and so on have been used to model it. In these studies, however, neither groups of individuals with emotion nor relations between individuals or constraints (from relations in individual dynamics) have been dealt with.

In Artificial Life, on the other hand, groups that consist of individuals with simple dynamics, relations generated through communications between the individuals, and constraints from relations in individual dynamics play major roles. However, emotional states and personalities of individuals have not been dealt with, although some studies on emotion have employed mutual actions between entities[3][4].

Some of the above models for emotion use production rules to make a stimulus from the environment correspond to an emotional state. We regard such correspondence as a finite state machine by regarding an internal state of a finite state machine as an emotional state of an individual. More specifically, an input into this finite state machine is regarded as a stimulus from the environment, and an output from the finite state machine is regarded as an action of an individual.

In this paper, we propose a simple representation of an individual dynamics by using a stochastic automaton and a model of a social group consisting of individuals represented by automatons, and investigate properties in the model. In particular, we focus on relations between individuals and on generating these relations based on an analogy from the theory on attitude changes in social psychology.

2 Representation of a Group of Individuals based on a Stochastic Automaton

In this section, we define a representation of an individual with emotional states and a certain personality by a stochastic automaton.

2.1 Representation of an Individual by a Stochastic Automaton

Let $E = \{E_1, E_2, \ldots, E_m\}$ be a set of symbols that represent emotional states and $A = \{A_1, A_2, \ldots, A_m\}$ be a set of symbols that represent actions. We define our stochastic automaton whose internal state space is E and whose input and output space is A as follows:

$$
\begin{aligned}
& AT(r,f) = \\
& \quad \{E, A, AC(r,\cdot,\cdot), EM(f,\cdot,\cdot), EF, \pi(f,r,\cdot)\} \\
& r \in [0,1]^D,\ f \in [0,1], \\
& AC : [0,1]^D \times E \times A \rightarrow [0,1], \\
& AC(r, E_i, A_j) : \text{ Probability that} \\
& \quad \text{the output is } A_j \\
& \quad \text{when the internal state is } E_i, \\
& EM : [0,1] \times A \times A \times E \rightarrow [0,1], \\
& EM(f, A_j, A_k, E_l) : \text{ Probability that} \\
& \quad \text{the next internal state is } E_l \\
& \quad \text{when the input is } A_j \text{ and the output is } A_k, \\
& EF(\in E)\text{: Halting tate,} \\
& \pi(f,r,E_i) : \text{ Probability that} \\
& \quad \text{the initial internal state is } E_i \\
& \left(\begin{array}{l} \sum_{j=1}^{n} AC(r,E_i,A_j) = 1 \\ \sum_{l=1}^{m} EM(f,A_j,A_k,E_l) = 1 \\ (i = 1,\ldots,m, j,k = 1,\ldots,n), \\ \sum_{i=1}^{m} \pi(F,r,E_i) = 1 \end{array} \right)
\end{aligned}
\tag{1}
$$

Here, r represents the personality parameter and f represents the attitude towards an object for output.

Let $em(t) \in E$ be the internal state at discrete time t, $ac(t) \in A$ be the output at t, and $in(t) \in A$ be the input at t. Then, the relation $em(t)$, $ac(t)$ and $in(t)$ share is given as follows:

$$\begin{aligned}
&Prob(em(0) = E_i) = \pi(f, r, E_i) \qquad (2)\\
&Prob(em(t+1) = E_i) = EM(f, in(t), ac(t), E_i)\\
&Prob(ac(t) = A_j) = AC(r, em(t), A_j)\\
&\quad (i = 1, \ldots, m,\ j = 1, \ldots, n,\ t = 0, 1, \ldots)
\end{aligned}$$

Let $TRE_k(f, r) \in M_m(\boldsymbol{R})$ be the state transition probability matrix in the case the input is A_k. From (1), we can get $TRE_k(f, r)$ as follows:

$$\begin{aligned}
TRE_k(f, r) &= (tre_k(f, r)_{ij}) \in M_m(\boldsymbol{R})\\
tre_k(f, r)_{ij} &= Prob(E_i \to E_j \mid input = A_k) \qquad (3)\\
&= \sum_{l=1}^{n} AC(r, E_i, A_l) EM(f, A_k, A_l, E_j)\\
&\quad (k = 1, \ldots, n,\ i, j = 1, \ldots, m)
\end{aligned}$$

$$\left(\begin{array}{l}
i.e.,\\
TRE_k(f, r) = AC(r) EM^k(f)\ (k = 1, \ldots, n),\\
AC(r) \in M(\boldsymbol{R} : m, n), EM^k(f) \in M(\boldsymbol{R} : n, m),\\
(AC(r))_{ij} = AC(r, E_i, A_j)\\
\left(EM^k(f)\right)_{ij} = EM(f, A_k, A_i, E_j)\\
\text{Here, } M_{ij} \text{ is the } (i, j) \text{ component of Matrix } M
\end{array}\right)$$

We represent a conversation between an individual with personality r and another individual with attitude f by regarding $AT(r, f)$ as the conversational dynamics of the individuals. $em(t)$ is regarded as the emotional state of one individual at time t, $ac(t)$ as the action of one individual at time t, and $in(t)$ as the action of the other individual at atime t.

2.2 Representation of a Group of Individuals

We define a group of individuals with emotional states in E and actions in A, by using the stochastic automaton in subsection 2.1 as follows:

$$\begin{aligned}
&Ind_i =\\
&\quad \{f_i(t), em_i(t), ac_i(t), r_i, AT(r_i, \cdot), Fr_i(t), G_i(\cdot)\}\\
&f_i(t) = (f_{i1}(t), f_{i2}(t), \ldots, f_{iL}(t)) \in [-1, 1]^L \qquad (4)\\
&em_i(t) \in E,\ ac_i(t) \in A,\ Fr_i(t) \in [1, \infty)\\
&r_i \in [0, 1]^D,\ G_i : [1, \infty) \times E \times A \to [1, \infty)\\
&\quad (i = 1, \ldots, L,\ L \geq 3,\ t = 0, 1, \ldots)
\end{aligned}$$

Here, $f_i(t)$ is the vector for the attitude of the i–th individual toward the other individual, $em_i(t)$ is the emotional state of the i–th individual, and $ac_i(t)$ is the action of the i–th individual at time t. Moreover, $Fr_i(t)$ is the frustration of the i–th individual at time t, r_i is the personality parameter of the i–th individual, and G_i is a function modifying $Fr_i(t)$. G_i is defined as follows:

$$G_i(Fr, e, a) = \begin{cases} 1.0 & (e, a) \in FRSR_i \\ Fr + C_i & (e, a) \in FRSI_i \\ Fr & \text{Otherwise} \end{cases} \qquad (5)$$

$$\text{for } (Fr, e, a) \in [1, \infty) \times E \times A \quad (i = 1, \ldots, L)$$

$$\left(\begin{array}{l} FRSR_i, FRSI_i \subset E \times A,\\ FRSR_i \cap FRSI_i = \emptyset, C_i > 0 \end{array}\right)$$

Equation (5) represents the situation in which the frustration is refreshed when a particular action is done at a particular emotional state, it is increased or maintained in the other cases.

The major objective in this paper is to regard $f_i(t)$ as the relations between individuals and to investigate the dynamics of $f_i(t)$. We define the procedure for the generation of the relations between these individuals as follows:

(a) Select any pair of individuals and execute the conversation between the selected individuals. (Note that the other individuals do not change either their states or attitudes and do not output any actions during the conversation between the selected individuals.)
(b) Modify the attitude of one individual toward the other in (a) based on their emotional states at the end of the conversation.
(c) Modify the attitudes of the other individuals toward the individuals in (a) based on the attitudes modified in (b)
(d) Repeat (a),(b), and (c)

2.3 Representation of a Conversation between Individuals

We define the conversation starting at time t between Ind_p and Ind_q $(p, q = 1, \ldots, L, p \neq q)$ as follows:

$$\begin{aligned}
&f'_{pq}(t+\tau) = \frac{f_{pq}(t) + 1}{2Fr_p(t+\tau)}, f'_{qp}(t+\tau) = \frac{f_{qp}(t) + 1}{2Fr_q(t+\tau)},\\
&Prob(em_p(t) = E_i) = \pi(f'_{pq}(t), r_p, E_i)\\
&Prob(em_q(t) = E_i) = \pi(f'_{qp}(t), r_q, E_i)\\
&Prob(ac_p(t+\tau) = A_j) = AC(r_p, em_p(t+\tau), A_j)\\
&Prob(ac_q(t+\tau) = A_j) = AC(r_q, em_q(t+\tau), A_j)\\
&Prob(em_p(t+\tau+1) = E_i) = \qquad (6)\\
&\quad EM(f'_{pq}(t+\tau), ac_q(t+\tau), ac_p(t+\tau), E_i)\\
&Prob(em_q(t+\tau+1) = E_i) =\\
&\quad EM(f'_{qp}(t+\tau), ac_p(t+\tau), ac_q(t+\tau), E_i)\\
&Fr_p(t+\tau+1) =\\
&\quad G_p(Fr_p(t+\tau), em_p(t+\tau), ac_p(t+\tau))\\
&Fr_q(t+\tau+1) =\\
&\quad G_q(Fr_q(t+\tau), em_q(t+\tau), ac_q(t+\tau))\\
&\quad (i = 1, \ldots, m, j = 1, \ldots, n, \tau = 0, 1, \ldots)
\end{aligned}$$

Here, $f'_{\cdot\cdot}(t+\tau)$ is the value with which the attitude $f_{\cdot\cdot}(t)$ is normalized in $[0, 1]$ and which is affected by the frustration $Fr_{\cdot}(t+\tau)$.

The conversation in equation (6) finishes when the conversation continues during a given time T (when $t = \tau$) or when $em_p(t+\tau) = em_q(t+\tau) = EF$. When the conversation finishes, the attitudes towards one another are modified based on the emotional states as follows:

$$\begin{aligned}
&f_{pq}(t+\tau) =\\
&\quad H(f_{pq}(t) + prf_p(r_p, em_p(t+\tau)))\\
&\quad (p, q = 1, \ldots, L,\ q \neq p) \qquad (7)\\
&prf_p : [0, 1]^D \times E \to \mathrm{R},
\end{aligned}$$

$$H : \mathrm{R} \to \mathrm{R}, H(x) = \begin{cases} -1 & (x < -1) \\ x & (-1 \leq x \leq 1) \\ 1 & (x > 1) \end{cases}$$

Equation (7) shows that when the conversation finishes, the attitude of the individual that had executed the conversation toward the other is increased or decreased dependent on the personality and emotional state of that individual at the end of the conversation.

If $f'_{pq}(t+\tau)$ and $f'_{qp}(t+\tau)$ are constant during the conversation, we can represent the conversation in equation (6) by a finite Markov chain whose state space is $E \times E$ as follows:

$$\begin{aligned}
&Prob\left((E_i, E_j) \to (E_k, E_l)\right) = \\
&\sum_{a=1}^{n}\sum_{b=1}^{n} \begin{pmatrix} Prob(A_a \mid E_i \text{ in } Ind_p) \\ \times Prob(A_b \mid E_j \text{ in } Ind_q) \\ \times Prob(E_i \to E_k \mid A_b \text{ in } Ind_p) \\ \times Prob(E_j \to E_l \mid A_a \text{ in } Ind_q) \end{pmatrix} \\
&= \sum_{a=1}^{n} AC(r_p, E_i, A_a)\, tre_a(r_q, f'_{qp}(t))_{jl} \\
&\quad \times \sum_{b=1}^{n} AC(r_q, E_j, A_b)\, tre_b(r_p, f'_{pq}(t))_{ik} \qquad (8) \\
&= \sum_{a=1, v=1}^{n} \begin{pmatrix} AC(r_p, E_i, A_a) \times AC(r_q, E_j, A_v) \\ \times EM(f'_{qp}(t), A_a, A_v, E_l) \end{pmatrix} \\
&\times \sum_{b=1, s=1}^{n} \begin{pmatrix} AC(r_q, E_j, A_b) \times AC(r_p, E_i, A_s) \\ \times EM(f'_{pq}(t), A_b, A_s, E_k) \end{pmatrix} \\
&\quad (i, j, k, l = 1, \ldots, m) \\
&\begin{pmatrix} i.e., \\ Prob\left((E_i, E_j) \to (E_k, E_l)\right) = \\ \quad \left(AC(r_p) EM_l(f'_{qp}(t)) tr(AC(r_q))\right)_{ij} \\ \quad \times \left(AC(r_q) EM_k(f'_{pq}(t)) tr(AC(r_p))\right)_{ji} \\ EM_k(f) \in M_n(\boldsymbol{R}) \ (k = 1, \ldots, m) \\ (EM_k(f))_{ij} = EM(f, A_i, A_j, E_k) \\ tr(M): \text{ the transpose of Matrix } M \end{pmatrix}
\end{aligned}$$

3 Generation of Relations between Individuals based on an Analogy from Social Psychology

During a conversation between one individual and another in equation (6), we do not change the emotional states of the other individuals and do not deal with their output actions. At the end of the conversation, they modify their attitudes towards the two individuals that did the conversation based on the congruity theory[2].

3.1 Modification of Relations based on the Congruity Theory

The congruity theory predicts attitude changes in communications based on cognitive consistency. Cognitive consistency is based on the idea that humans have a basic requirement: they want to maintain consistency in their beliefs, attitudes, and actions for objects; if inconsistencies exist, they cause displeasure. Humans are motivated to reduce displeasure.

In the congruity theory or some theories on cognitive consistency, a person (P), a concept toward which P has an attitude (C), and a message source that refers to C (S) are dealt with. In these theories, the balance in the attitude of P for C (PC), that of P for S (PS), and the message of S for C (SC) are major problems.

The balance theory defines that if the sign of the product of PC, PS, and SC is positive, the situation is balanced; if it is negative, the situation is inbalanced.

In the congruity theory, the changes in values of PC and PS is determined to balance the situation based on the following equations (from [2]):

$$\begin{aligned}
&\text{The Change in } PS = W(SC, PC, PS) \\
&= \begin{cases} \frac{|PC|}{|PC|+|PS|}(PC - PS) & (SC > 0) \\ \frac{|PC|}{|PC|+|PS|}(-PC - PS) & (SC < 0) \end{cases} \qquad (9) \\
&\text{The Change in } PC = W(SC, PS, PC)
\end{aligned}$$

If SC is positive, PC and PS are modified to the same value. If SC is negative, PC is modified to a value whose absolute value is the same as that of PS and whose sign is the reverse of that of PS: that is, the attitudes are modified so that the situation is balanced and the bias between the attitudes is canceled.

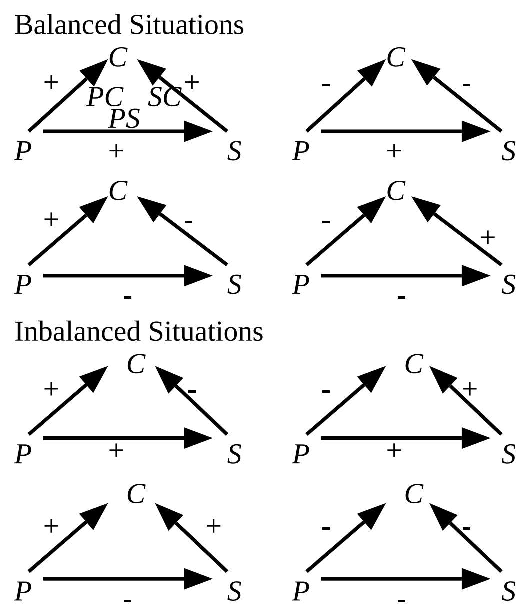

Figure 1: Balanced and Inbalanced Situations in the Balance Theory (from [2])

Now, we assume that Ind_p and Ind_q start the conversation at time t and finish at time $t + \tau$. We regard the attitude of Ind_p toward Ind_q as the message from Ind_p to Ind_q and the attitude of Ind_q toward Ind_p as the message from Ind_q to Ind_p, and define the modification of the attitudes of $Ind_s (s \neq p, q)$ based on (9) in the following:

$$f_{sp}(t+\tau) \quad = \quad H\left(f_{sp}(t) + \frac{1}{2}W(f_{pq}(t+\tau), f_{sq}(t), f_{sp}(t))\right.$$

$$+ \quad \frac{1}{2}W(f_{qp}(t+\tau), f_{sq}(t), f_{sp}(t))\Big) \qquad (10)$$

$$f_{sq}(t+\tau) \quad = \quad H\left(f_{sq}(t) + \frac{1}{2}W(f_{pq}(t+\tau), f_{sp}(t), f_{sq}(t))\right.$$

$$\left. + \quad \frac{1}{2}W(f_{qp}(t+\tau), f_{sp}(t), f_{sq}(t))\right)$$

$$(\text{Here, } W(0,\cdot,\cdot) \equiv 0,\ W(\cdot,0,0) \equiv 0)$$

Here, H is the normalization function defined in (7).

3.2 Balanced Situations in the group

We generate the relations between the individuals by repeating the conversation in (6) and the modifications of the relations in (7) and (10). When the relation for any combination of three individuals is a balanced situation in the sense of the balance theory in 3.1 ($i.e.$, $f_{pq}(t)f_{sp}(t)f_{sq} > 0$ for $\forall p\ \forall q(\neq p)\ \forall s(\neq p, \neq q)$), we say that the group is balanced; otherwise, we say that the group is inbalanced.

Now, we assume that the group is balanced. By this assumption, the i–th individual and the j–th individual exist such that the i–th individual has a positive attitude toward the j–th individual. If the other k–th individual has a positive attitude toward the i–th individual, it also has a positive attitude toward the j–th individual, and thus the j–th individual has a positive attitude toward the i-th individual by the assumption. Similarly, if the k–th individual has a negative attitude toward the i–th individual, it also has a negative attitude toward the j–th individual; the j–th individual has a positive attitude toward the i–th individual. Furthermore, if another l–th individual has an attitude toward the i-th and j–th individuals whose sign is the same as that of the k-th individual, the k–th and l–th individuals have a positive attitude for each other. Thus, if the group is balanced, only the following two cases are possible:

1. Case 1: Every individual has a positive attitude toward the other individuals.

2. Case 2: The group is separated into two subgroups. Every individual in one subgroup has a positive attitude toward the other individuals in the same subgroup and a negative attitude toward all individuals in the other subgroup.

For each $i(> 1)$, we assign 0 if the i–th individual belongs to the subgroup including the 1st individual ($i.e.$, $f_{i1}(t) > 0$) and 1 if the i–th individual belongs to the subgroup not including the 1st individual ($i.e.$, $f_{i1}(t) \leq 0$). By using bit value $b_i (i = 2, \ldots, L)$, we can number all balanced situations with the following N:

$$N = \sum_{i=0}^{L-2} b_{L-i}2^i,\ b_i = \begin{cases} 0 & (f_{i1}(t) > 0) \\ 1 & (f_{i1}(t) \leq 0) \end{cases} \qquad (11)$$

Thus, a total of 2^{L-1} balanced situations are possible. Figure 2 shows the case of $L = 4$.

Moreover, we define the degree of balance in the group at time t as follows:

$$DB(t) = \frac{1}{L(L-1)(L-2)} \times \qquad (12)$$

$$\sum_{\substack{i \neq j \\ k > j, k \neq i}} (f_{ij}(t)f_{ik}(t)f_{kj}(t) + f_{ij}(t)f_{ik}(t)f_{jk}(t))$$

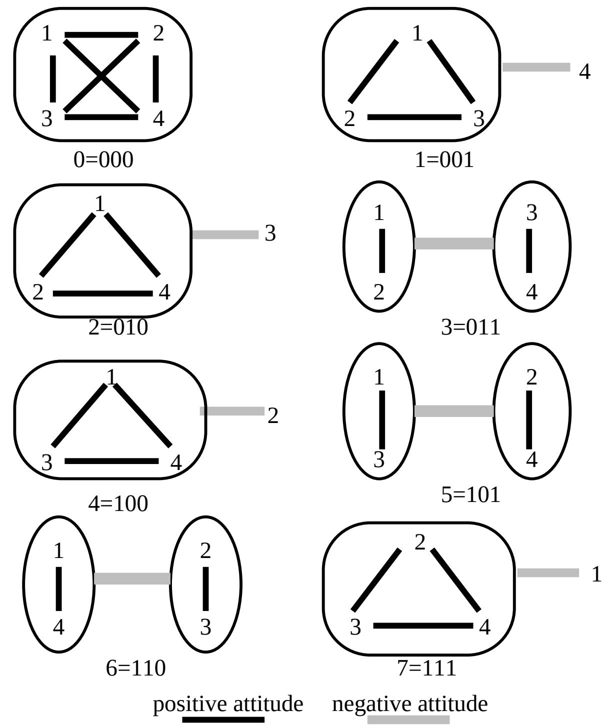

Figure 2: All Possible Balanced Situations and their Numberings (the case of $L = 4$)

This degree of balance can also be defined for inbalanced situations. By the definition, $DB(t)$ has the maximum value of 1.0 if every individual has the maximum attitude of 1.0 toward the other individuals and has the minimum value of -1.0 if every individual has the maximum attitude of -1.0 toward the other individuals.

4 One Example

The concrete description of the model we propose in Sections 2 and 3 depends on the following elements:
The set of emotional states for the stochastic automaton: E in (1)
The set of action for the stochastic automaton: A in (1)
The dimension of the personality parameters: D in (1)
The halting state of the stochastic automaton: EF in (1)
The initial state probability dependent on personality r and attitude f: $\pi(r, f, \cdot)$ in (1)
The emotion–action probability matrix dependent on personality r: $AC(r)$ in (3)
The action–emotion probability matrices dependent on attitude f: $EM^i(f)$ $(i = 1, \ldots, n)$ in (3)
The degree of increase of frustration: C_p $(p = 1, \ldots, L)$ in (5)
The set of pairs of emotional state and action that refreshes the frustration: $FRSR_p$ $(p = 1, \ldots, L)$ in (5)

The set of pairs of emotional state and action that increases the frustration: $FRSI_p$ $(p = 1, \ldots, L)$ in (5)
The functions that determine the change of attitude at the end of conversation dependent on personality r: $prf_p(r, \cdot)$ $(p = 1, \ldots, L)$ in (7)

We give one concrete example for the above elements in the following:

$$E_1 = \text{"}anger\text{"}, E_2 = \text{"}hatred\text{"}, E_3 = \text{"}fear\text{"},$$
$$E_4 = \text{"}pleasure\text{"}, E_5 = \text{"}sadness\text{"},$$
$$E_6 = \text{"}neutrality\text{"}$$
$$A_1 = \text{"}rebound\text{"}, A_2 = \text{"}cooperation\text{"},$$
$$A_3 = \text{"}disregard\text{"}$$
$$EF = E_4 = \text{"}pleasure\text{"},\ D = 1$$
$$\begin{pmatrix} \pi(f,r,E_1) \\ \pi(f,r,E_2) \\ \pi(f,r,E_3) \\ \pi(f,r,E_4) \\ \pi(f,r,E_5) \\ \pi(f,r,E_6) \end{pmatrix} = \begin{pmatrix} 0.0 \\ (1-f)r \\ 1-r \\ 0.0 \\ 0.0 \\ fr \end{pmatrix}$$
$$AC(r) = \begin{pmatrix} 0.5r & 1-r & 0.5r \\ r & 0.5(1-r) & 0.5(1-r) \\ 0.5r & 1-r & 0.5r \\ 0.1(1-r) & 0.8+0.2r & 0.1(1-r) \\ 0.1r & 1-0.9r & 0.8r \\ 0.3r & 1-0.7r & 0.4r \end{pmatrix}$$
$$EM^1(f) = \begin{pmatrix} 1-f & 0.0 & 0.0 & 0.0 & f & 0.0 \\ 1-f & f & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & f & 0.0 & 0.0 & 1-f \end{pmatrix}$$
$$EM^2(f) = \begin{pmatrix} 0.0 & 0.0 & f & 0.0 & 0.0 & 1-f \\ 0.0 & 0.0 & 0.0 & f & 0.0 & 1-f \\ 0.0 & 0.0 & f & 0.0 & 0.0 & 1-f \end{pmatrix}$$
$$EM^3(f) = \begin{pmatrix} f & 0.0 & 0.0 & 0.0 & 0.0 & 1-f \\ 1-f & 0.0 & 0.0 & 0.0 & f & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & f & 1-f \end{pmatrix}$$
$$FRSR_p = \left\{ \begin{array}{l} (E_1, A_1), (E_2, A_1), (E_4, A_4), \\ (E_5, A_1), (E_5, A_2) \end{array} \right\}$$
$$FRSI_p = \left\{ \begin{array}{l} (E_1, A_2), (E_2, A_2), (E_2, A_3), \\ (E_3, A_1), (E_3, A_2), (E_3, A_3), \\ (E_4, A_1), (E_4, A_3) \end{array} \right\}$$
$$C_p = 1.0 \quad (p = 1, \ldots, L)$$
$$(prf_p(r, E_1), \ldots, prf_p(r, E_6)) =$$
$$(1-r)(-0.5, -0.5, -0.5, 0.5, -0.5, 0.0)$$

From the above probability matrices, we can get the state transition probabilities in the conversation in (8); in particular, the probability of transition from every state (E_i, E_j) to the halting state (EF, EF) in the following:

$$Prob(E_i, E_j \to EF, EF) =$$
$$f'_{pq}(t) f'_{qp}(t) \left(AC(r_p)_{i2}\right)^2 \left(AC(r_q)_{j2}\right)^2$$
$$(i, j = 1, \ldots, 6)$$

In this example, if the attitudes toward each other are positive, the conversation is easy to end at the halting state ("*pleasure*","*pleasure*"). Moreover, if the personalities are low, the action "*cooperation*" is easy to be selected, and thus the conversation is easy to end at ("*pleasure*","*pleasure*"). If the personality is low, however, the frustration tends to become high and the attitude drastically changes. In this case, the transition probabilities tend to change frequently and the group becomes unstable. If the personality is high, in contrast, the frustration tends not to become high and the attitude does not drastically change. Therefore, the transition probabilities tend not to change frequently. However, the action "*cooperation*" is not easy to be selected.

5 Simulations for the concrete model in Section 4

We executed simulations for the concrete model defined in Section 4 and investigated changes in the relations in the group. In the simulations, we let the longest conversation time T be 5 or 15 and the conversations for all pairs of individuals be one round. One hundred thousand rounds were executed. Moreover, we let τ_i $(i = 1, \ldots, 10^5)$ be the time when the i–th round finished.

In this paper, we focused on the simplest group which consists of three individuals with the same personality ($i.e., L = 3$, $r_1 = r_2 = r_3$). Note that the total number of balanced situations is 3.). We prepared nine kinds of personality parameters: $r_i = 0.1$, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9, and evaluated the rate at which each balanced situation in the group appeared through one hundred trials, the situation and the degree of balance in the group at each time τ_i $(i = 1, \ldots, 10^5)$ for each case.
(In the following figures, the horizontal axis is the trial number $(i = 1, \ldots, 10^5)$)

5.1 Results of Simulations

Table 1 shows the rate at which each situation in the group appeared through one hundred thousand rounds in one hundred trials for each case. Table 2 shows the average number of times that the situation changed and the average number of balanced situations appearing through one hundred thousand rounds in one hundred trials for each case.

When the personality was low and the longest conversation time was short, the situation in the group frequently transited between several situations and the group was unstable. Figure 3 shows one example of transitions in balanced situations in the case of $T = 5$ and $r_i = 0.2$. In this case, the situation frequently transited between all situations.

As the personality became higher, the rate at which situation 0 (the situation where all individuals had a positive attitude for each other) appeared became lower and the changes in situation became less. Figure 4 shows one example of transitions in balanced situations in the case of $T = 5$ and $r_i = 0.8$. In this case, the group situation quickly became one of the balanced situations other than at situation 0 and the group was stable.

r	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
[$T = 5$] Balanced Situation 0	12.2	9.8	2.6	0.3	0.0	0.0	0.0	0.0	0.0
[$T = 5$] Balanced Situation 1	30.1	30.3	31.6	33.6	36.3	34.9	27.2	26.7	23.6
[$T = 5$] Balanced Situation 2	27.1	31.1	31.9	30.5	34.7	27.6	38.6	36.0	39.4
[$T = 5$] Balanced Situation 3	29.5	28.3	33.7	35.5	28.9	37.5	34.2	37.3	37.0
[$T = 5$] Inbalanced Situation	1.1	0.5	0.2	0.1	0.0	0.0	0.0	0.0	0.0
[$T = 15$] Balanced Situation 0	91.8	91.3	96.8	84.1	72.1	41.4	3.0	0.0	0.0
[$T = 15$] Balanced Situation 1	2.2	4.0	2.0	5.5	11.6	16.9	30.1	34.0	31.0
[$T = 15$] Balanced Situation 2	3.1	3.0	1.2	6.4	6.4	21.3	38.4	35.0	31.0
[$T = 15$] Balanced Situation 3	2.9	1.7	0.0	4.0	9.9	20.4	28.5	31.0	38.0
[$T = 15$] Inbalanced Situation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 1: The rate (%) at which each situation appeared for each case

r	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
[$T = 5$] number of change	87.4	60.1	29.4	13.6	5.8	3.0	1.9	1.4	1.2
[$T = 5$] number of situations	4.0	4.0	4.0	3.8	3.0	2.2	1.7	1.3	1.2
[$T = 15$] number of change	3.0	1.4	1.1	1.1	1.2	1.2	1.4	1.3	1.2
[$T = 15$] number of situations	1.9	1.3	1.1	1.1	1.2	1.2	1.4	1.3	1.1

Table 2: The average number of times that the situation changed and the average number of balanced situations appearing for each case

When the personality was low and the longest conversation time was long, the rate at which situation 0 appeared was very high and the change of the situation was little. Figure 5 shows one example of transitions in balanced situations in the case of $T = 15$ and $r_i = 0.2$. In this case, the group situation quickly became like situation 0 and the group was stable. As the personality became higher, the rate at which situation 0 appeared became lower like in the case where the longest conversation time was shorter.

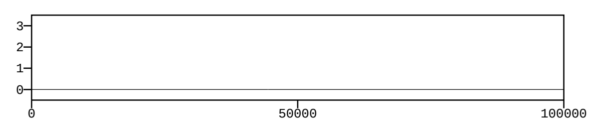

Figure 5: One Example of Transitions in the Situations in the Case of $T = 15$ and $r_i = 0.2$

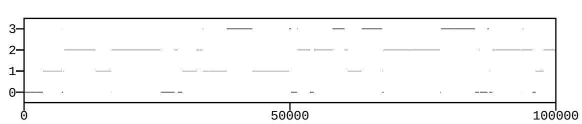

Figure 3: One Example of Transitions in the Situations in the Case of $T = 5$ and $r_i = 0.2$ (the virtual axis: the situation number defined in (11))

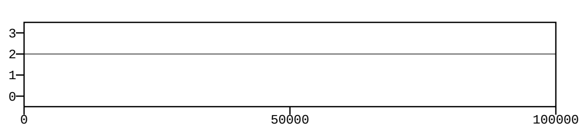

Figure 4: One Example of Transitions in the Situations in the Case of $T = 5$ and $r_i = 0.8$

Figures 6, 7, 8, and 9 show transitions in the degree of balance in the group for the case of $T = 5$ and $r_i = 0.2$, $T = 5$ and $r_i = 0.8$, $T = 15$ and $r_i = 0.2$, and $T = 15$ and $r_i = 0.8$. When the personality was low and the longest conversation time was short, the degree of balance changed more widely than the other case and the group showed instability. As the personality became higher and the longest conversation time became longer, the width in the change of the degree of balance became more narrow and the group became more stable.

5.2 Discussion

For the above results, we can consider the following discussion.

In the concrete mode defined in Section 4, the individual with a low personality tends to increase the frustration and change the attitude toward its conversation partner frequently. Thus, when the personality is low, the situation frequently changes. However, because the individual with a low personality tends to select a cooperation action, the frustration tends to decrease and the conversation tends to end at the halting state when the

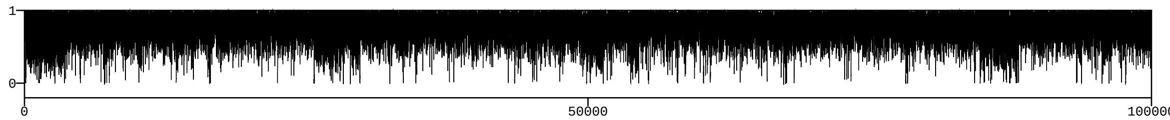

Figure 6: Transition in the Degree of Balance in the Group for the Case of $T = 5$ and $r_i = 0.2$ (the vertical axis: the degree of balance in the group $DB(\tau_i)$ defined in (12))

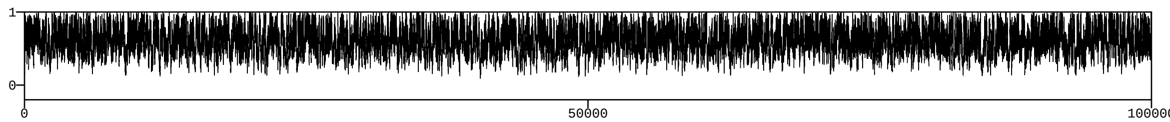

Figure 7: Transition in the Degree of Balance in the Group for the Case of $T = 5$ and $r_i = 0.8$

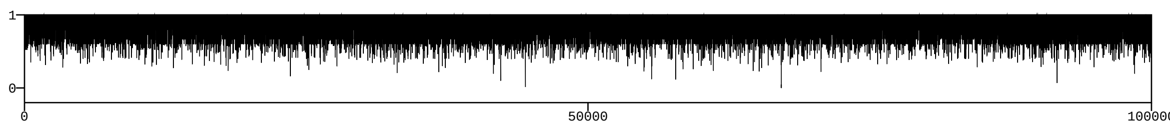

Figure 8: Transition in the Degree of Balance in the Group for the Case of $T = 15$ and $r_i = 0.2$

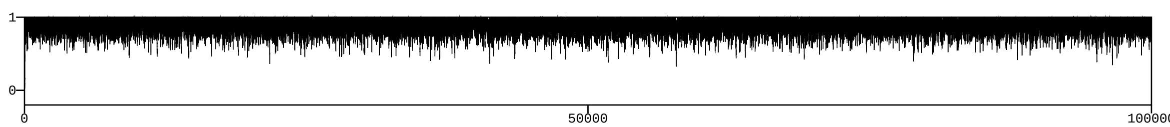

Figure 9: Transition in the Degree of Balance in the Group for the Case of $T = 15$ and $r_i = 0.8$

longest conversation time is long.

Figures 10, 11, 12, and 13 show transitions in the average frustration on three individuals for the case of $T = 5$ and $r_i = 0.2$, $T = 5$ and $r_i = 0.8$, $T = 15$ and $r_i = 0.2$, and $T = 15$ and $r_i = 0.8$. In fact, the frustration is reduced more as the personality is lower and the longest conversation time is longer. Thus, the situation where all individuals have a positive attitude toward each other easily appears in the case where the personality is low. On the other hand, the individual with a high personality tends not to increase the frustration and not to change the attitude toward its conversation partner frequently. Thus, the situation does not frequently change. However, because the individual with a high personality tends not to select a cooperation action, the group is easily separated.

6 Conclusion

We proposed a model representing a group that consistes of individuals with emotional states by using a stochastic automaton and an analogy of social psychology. Moreover, we investigated the properties of the model by executing simulations for a concrete case.

This model imitates only a part of the relationship between actions and emotional states in humans, and does it quite wildly. Furthermore, there is no guarantee that the properties in the model reflect some social phenomena in the real world. In order to reflect real social phenomena, we need to consider many levels of emergence: the relationship between person perception in individuals and generation of structures of society, the relationship between desires in individuals and survival strategies of individuals under structures of society, and so on.

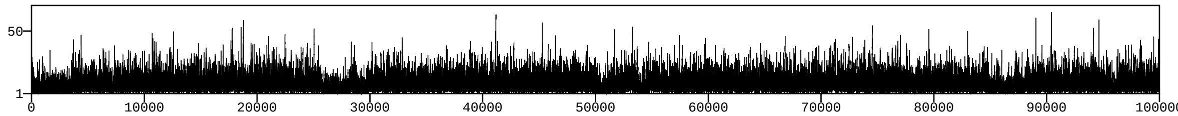

Figure 10: Transition in the Average Frustration on Three Individuals for the Case of $T = 5$ and $r_i = 0.2$ (the vertical axis: the average of $Fr_p(\tau_i)$ defined in (1) on all of the individuals)

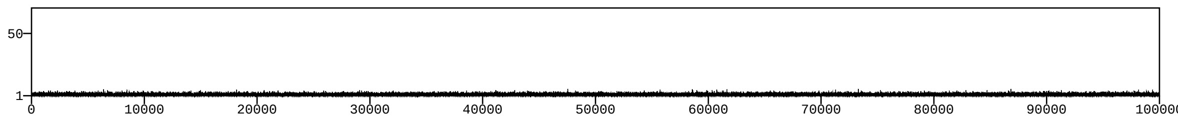

Figure 11: Transition in the Average Frustration on Three Individuals for the Case of $T = 5$ and $r_i = 0.8$

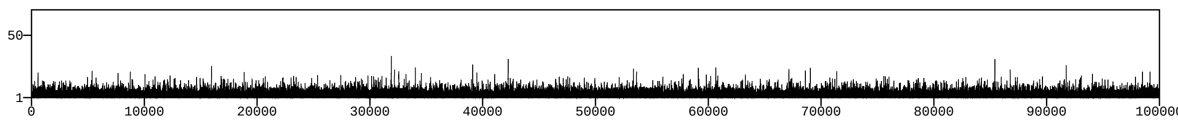

Figure 12: Transition in the Average Frustration on Three Individuals for the Case of $T = 15$ and $r_i = 0.2$

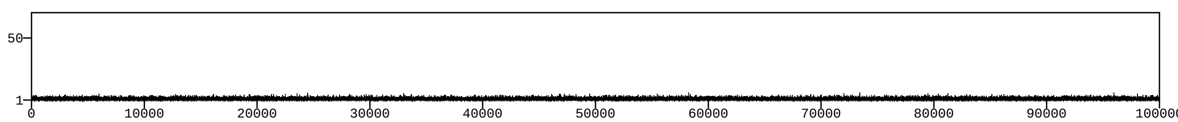

Figure 13: Transition in the Average Frustration on Three Individuals for the Case of $T = 15$ and $r_i = 0.8$

Acknowledgments

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