Crowd Behavior in Alternative@
Conflicts in the Decision-making between an Individual and the Group

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Abstract: Crowd behavior depends on social interaction among group members. In particular, there has been considerable interest in the decision-making of such a group on their movement during travel. Here we discuss the decision-making processes in choice selection between two things, i. .e., alternative, by means of numerical simulations based on social force model developed by Helbing et al. This allows us to introduce an individual decision-making process into the decision-making of the whole group through psychological parameter, the so-called dependence p, equivalent to panic parameter in an emergency evacuation. We demonstrate the conflict that arises in the decision-making between an individual and the group in alternative. In addition, we reconfirmed a similar stochastic collective behavior in the decision-making processes observed by Couzin et al. in traveling animals at the large p regimes even if there are no leaders in the group. On the other hand, individualistic behavior is pronounced in smaller p regimes. This feature prevents the formation of group, leading to no collective decision-making anymore. Therefore, the parameter p is a key to consider in the decision-making of both the individual and the group.

1 INTRODUCTION

Human behaviors in social activities are, in general, incredibly complicated so that no direct approach has ever established to understand them. However, recent advances in information technology enable us to investigate tremendously huge data behind human behaviors, the so-called "big data". Among these is the crowd behavior which has become the primary issue in the study of fundamental attributes and characteristics of humans in social interaction among group members. As a matter of fact, collective motion and self-organized behaviors have become a major objective in many fields such as theoretical biology (Warburton and Lazarus, 1991), biological physics (Vicsek et al., 1995) and control engineering (Leonard and Fiorelli, 2001).

In particular, there has been considerable interest in the decision-making of such a group, for example, on their movement during travel (Couzin et al., 2005). Here we discuss the decision-making processes in the simplest situation such as in making a choice between two things, i. e., alternative, on the movement by means of numerical simulations based on social force model developed by Helbing et al. (Helbing et al., 2000) from the viewpoint of conflicts in the decision-making between an individual and the group.

Couzin et al. have succeeded to elucidate the decision-making of an animal group with effective leaders. However, an essential element in the idea behind the decision making is conclusively missing in their approach for our purpose, .i.e., there are no individual free will in each agent which plays a role as follower. In addition, flocking was also assumed in their study since a cohesive force has been introduced in the beginning. Thereby, it was difficult to discuss the conflicts in the decision-making between an individual and the group. However, the social force model has allowed us to study the decision-making processes ranging from microscopic (individual) to macroscopic (group) scales as a whole since it is, in principle, able to introduce an individual free will in each agent.

2 AGENT-BASED SIMULATIONS

Suppose that a group consisting of N individuals (agents here) travels in two possible pathways similar to the situation originally set by Couzin et al. as

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shown in Fig. 1. In contrast to them, this study is made different in such a way that there are no informed leaders and that each agent has his preferred direction. By reason of social interaction, the individual must decide whether he follows or not the preference of the others from time to time. In turn, this can affect the group movement which may influence the movement of individuals as well. Thus, the collective decision primarily depends on the individual dependence to others as better understood in psychology. In our numerical simulation, the panic parameter introduced by Helbing et al. in their study of escape panic plays a role as the i-th individual dependence p_i defined through the desired direction $\boldsymbol{e}_i^0(t)$ in the next section.

2.1 Social Force Model

There are several approaches to simulate social behaviors of animals including human such as an agent-based simulation (Reynolds, 1987) and particle swarm optimization (Kennedy and Eberhart, 1995). Here we employ a social force model (Helbing et al., 2000) based on an agent-based simulation to introduce individual will or preference into each agent as shown in the equations below. Social behavior of the i-th individual agent is modeled by a particle with mass m_i and velocity $\boldsymbol{v}_i$ influenced by both psychological and social forces, and is then governed by the equation of motion with appropriate forces given as

$$m_i \frac{d\boldsymbol{v}_i}{dt} = \boldsymbol{f}_i^{will} + \sum_j \boldsymbol{f}_{ij}. \tag{1}$$

The first term of the right hand side (rhs) in Eq.(1) stands for the force of agent's "*will*" expressed as

$$\boldsymbol{f}_i^{will} = m_i \frac{v_i^0(t)\boldsymbol{e}_i^0(t) - \boldsymbol{v}_i(t)}{\tau_i}. \tag{2}$$

Each agent, say i, likes to move with a certain desired speed v_i^0 in a certain direction $\boldsymbol{e}_i^0$ expressed as

$$\boldsymbol{e}_i^0(t) = Norm[(1-p_i)\boldsymbol{e}_i + p_i \langle \boldsymbol{e}_j^0(t) \rangle_i] \tag{3}$$

where $Norm(\boldsymbol{z}) = \boldsymbol{z}/|\boldsymbol{z}|$ denotes normalization of a vector $\boldsymbol{z}$. The unit vector $\boldsymbol{e}_i$ stands for the preferred direction of i-th agent and $\langle \boldsymbol{e}_j^0(t) \rangle_i$ for the average direction of his neighbours j in a certain radius. The parameter p_i is the i-th individual dependence which plays a role as the individual decision-making. It is noteworthy that this parameter also determines the behaviors of either the individual or the group such that the individual behavior appears if p_i is low otherwise the herding behavior is exhibited if p_i is high as shown in Fig. 1. The time τ_i is a characteristic time required in changing the motion which will be described later.

On the other hand, the second term of the rhs in Eq. (1) describes the psychological force between two agents, i and j. These two agents are separated from each other brought by a repulsive force that is often employed by a typical example expressed as,

$$\boldsymbol{f}_{ij} = A_i e^{(r_{ij}-d_{ij})/B_j} \boldsymbol{n}_{ij} \tag{4}$$

where A_i and B_i denote the interaction strength and the range of the repulsive interaction, respectively. r_{ij} is the sum of the their radii r_i and r_j, i.e. $r_{ij} = r_i + r_j$. d_{ij} is the distance between agent i and agent j, and $\boldsymbol{n}_{ij} = (\boldsymbol{r}_i - \boldsymbol{r}_j)/d_{ij}$ with $\boldsymbol{r}_{i(j)}$ being a position vector for agent $i(j)$ denotes a normalized vector pointing from agent i to agent j.

2.2 Equation of Motion for a Group

Now let us consider the collective behaviors of agents in alternative. This is done using the concept for the motion of the center of mass in a system of particles. Summing all over the equations of motion of an individual agent in Eq. (1) results to:

$$\sum_i m_i \frac{d\boldsymbol{v}_i}{dt} = \sum_i \boldsymbol{f}_i^{will} + \sum_{ij} \boldsymbol{f}_{ij}. \tag{5}$$

By using the definition of center of mass $M\boldsymbol{r}_G = \sum_i m_i \boldsymbol{r}_i$ with $M = \sum m_i$ and $\boldsymbol{v}_G \equiv d\boldsymbol{r}_G/dt$, as well as the relation in the law of action-reaction $\sum_{ij} \boldsymbol{f}_{ij} = 0$, which yields,

$$M\frac{d\boldsymbol{v}_G}{dt} + M\frac{1}{\tau}\boldsymbol{v}_G(t) = \frac{1}{\tau}\sum_i m_i v_i^0(t)\boldsymbol{e}_i^0(t) \tag{6}$$

under the assumption that the characteristic time τ_i and the dependence p_i are equal in all agents ($\tau = \tau_i$ and $p = p_i$ for $i = 1, 2, \cdots, N$). The second term of the left hand side (lhs) in Eq. (6) is nothing but the friction term as represented by the friction coefficient $1/\tau$. While the terms in the rhs of Eq. (6) characterize the driving forces due to individual agents with free will. Expanding further the rhs of Eq. (6) gives,

$$\begin{aligned} &\sum_i m_i v_i^0(t)\boldsymbol{e}_i^0(t) \\ &= \sum_i m_i v_i^0(t)[(1-p)\boldsymbol{e}_i + p\langle \boldsymbol{e}_j^0(t)\rangle_i] \\ &= (1-p)\sum_i m_i(v_i^0(t)\boldsymbol{e}_i) + p\sum_i m_i v_i^0(t)\langle \boldsymbol{e}_j^0(t)\rangle_i \\ &= (1-p)M(v_G^0(t)\boldsymbol{e}_G) + pMv_G^0(t)\langle \boldsymbol{e}_j^0(t)\rangle, \end{aligned} \tag{7}$$

where we use again the definition of center of mass and large view radius approximation, i.e. $\langle \boldsymbol{e}_j^0(t)\rangle = \langle \boldsymbol{e}_j^0(t)\rangle_i, (i = 1, \cdots N)$. Note that there are no individual indices anymore in this expression. Incorporating

Eq. (7) into Eq. (6), we now have

$$M\frac{d\boldsymbol{v}_G}{dt}+M\frac{1}{\tau}\boldsymbol{v}_G(t)$$
$$=\frac{1}{\tau}\left\{(1-p)M(v_G^0(t)\boldsymbol{e}_G)+pMv_G^0(t)\langle\boldsymbol{e}_j^0(t)\rangle\right\}. \quad (8)$$

This expression is the first remarkable result of this paper. It describes the social behavior of a group regarded as *a single virtual agent with its own will* $v_G^0(t)$. The element $v_G^0(t)\boldsymbol{e}_G$ in the first term of the rhs of Eq. (8) denotes the free will of the virtual representative agent that determines the action in consultation with inherent members through the element $\langle\boldsymbol{e}_j^0(t)\rangle$ in the second term. Finally, it is regarded that this expression is formally true for whole ranges of p values and is highly effective when p values are large enough to form a group as mentioned above.

3 SIMULATION

Suppose that initially the agents ($N = 100$) are distributed randomly near the coordinate origin without touching each other. Their initial velocities are also random at an approximate rate of 1 m/s. The mass of each agent is 80 kg. The diameter r is 0.75m while the desired speed v^0 is 1 m/s. The acceleration time τ is 2.0 s. The parameters A and B are $A = 2000$N and $B = 0.08$m, respectively. The numerical calculations were carried out by Leap-Frog method (Birdsall and Langdon, 2004) with second-order accuracy in coordinates.

3.1 Group Formation: The Role of p

First of all let us consider the dependence p effect on social behaviors of agents. Figure 1 shows the trajectories for each agent with various p values at fixed agent number (60 agents among $N = 100$ agents) toward the destination A. At lower p values, an agent behaves independently with other agents which shows a trajectory of smooth curve (see Fig.1 (a):$p = 0.2$). On the other hand, the intermediate p values exhibit a trajectory of wavy curves (see Fig. 1(b):$p = 0.5$) since the agent is no longer independent of the other agents, and mutual interactions have caused unexpected behaviors. At higher p values, a number of agents cooperatively form a group, moving toward the destination A (see Fig. 1 (c): $p = 0.8$). Therefore, it is necessary to use higher values of psychological dependence p in numerical calculation based on social force model, in order to investigate the decision making of the group.

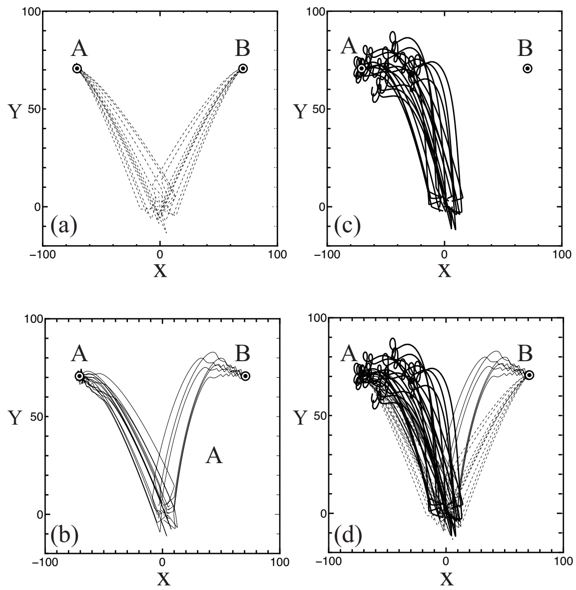

Figure 1: Trajectories for each agent from the origin to each destinations A or B. 60 agents intend to move the destination A. (a) $p = 0.2$, (b) $p = 0.5$, (c) $p = 0.8$ and (d) a superposition of all for easier comparison. X and Y denote coordinates.

3.2 Collective Decision Making in Alternative

Now let us discuss collective decision making in alternative. Figure 2 shows the number of agents who finally reached at the destination A ($N_A(t_{final})$) as a function of the number of agent initially intended to move toward the destination B ($N_{B0}(t_{initial})$). The dependence p is set to 0.9 to form a group. At $N_{B0} = 0$, all the agents naturally move to their common destination A. Upon increasing N_{B0} in the group, one can observe that the total number of agents N_A remains unchanged even if the N_{B0} increases until $N_{B0} \simeq 40$. Strictly speaking, the number of agents corresponding to the difference $N_A - N_{B0}$ follows the group behavior or group decision than their personal will. Therefore, this clearly shows an evidence of conflicts in the decision-making between an individual and the group which now highlights the second remarkable result of this paper. This is nothing but a majority rule in decision-making of human society. Over $N_{B0} > 40$, N_A rapidly decreases with an increasing N_{B0}. This means the group is split or a member leaves the group.

Finally, we present an interesting result of our agent-based simulation in decision making. Figure 3 shows again the trajectories of each agent at $p = 0.9$ when agents move as if a single object as mentioned previously. An important thing to say here is that group member is a fifty-fifty chance in following their

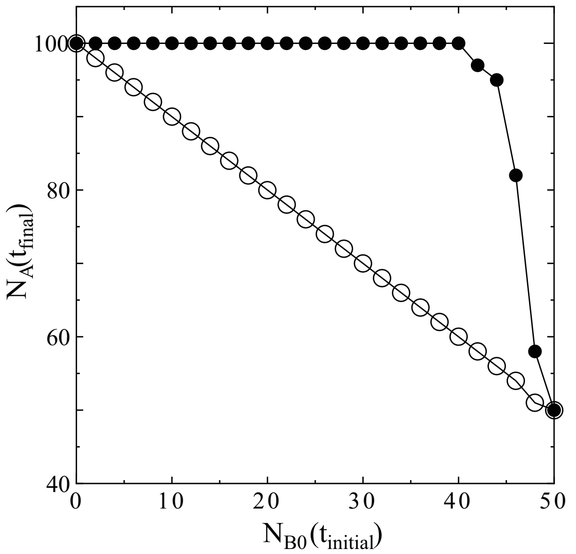

Figure 2: The total number of agents reached at the destination *A* versus the number of agents intended to go to the destination *B*. The solid circle represents the number of agents that have reached the destination *A* regardless of their own intended orientation direction. On the other hand, the circle stand for the number of agents reached at the destination *A* originally intended to go.

intended destinations. These two distinct results occasionally occur in our simulations. They resemble the stochastic phenomena that occur at unstable points like a saddle point in the double-minimum potential of classical mechanics. These results reveal an analogous study made by Couzin et al. such that the group changes from moving in the average preferred direction of all agents to selecting randomly one of the two preferred directions.

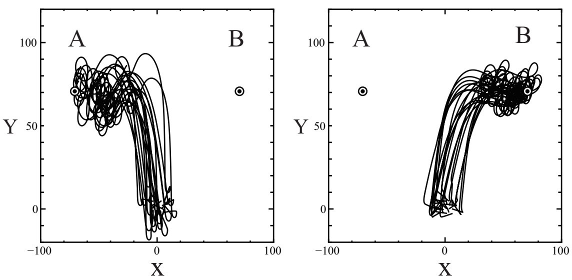

Figure 3: Trajectories for each agent from the origin to each destinations *A* or *B*. A half of all the agents (50 agents) intend to move the destination *A* at $p = 0.9$. *X* and *Y* denote coordinates. The group changes from moving in the average preferred direction of all agents to selecting randomly one of the two preferred directions on the way to final destination.

4 CONCLUSIONS

We have numerically investigated the crowd behaviors consisting of *N* agents with free will under the social forces in the case of choice selection between two things. We pointed out that social force model can naturally incorporate the individual free will of an agent into the decision making of the group to which he is part of. We have also derived an equation of motion for a group regarded as a single virtual agent which provides a strong tool for investigating collective dynamics of a system of agents. In addition, we have affirmed the study made by Couzin et al. that similar stochastic collective behaviour in decision-making of the group appears in the large *p* regimes by using social force model. On the other hand, individualistic behaviour is pronounced in smaller p_i regimes. This means that the formation of group is inhibited leading to no more collective decision-making anymore. Therefore, the dependence p_i is the key determinant to consider in the decision-making of both the individual and the entire group.

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