Simulation of Spatial Behavior Based on an Agent Model in Human-Agent Initial Interaction

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ABSTRACT

To design agent behavior in the initial phase of communication, we propose an agent model that possesses preferences for a relationship with a target. As an internal state, this model considers two relationship preferences with a target: control and acceptance. The agent's spatial behavior, which is represented by a change in its position, is determined based on its internal state and its positional relationship with the target. We investigated the interactions caused by the combination of the internal states of two agents through a computer simulation. We simplified the combinations of the internal states for the agent to reach its preferred position and clarified the position combinations that become unreachable. Based on these results, we discussed the change of the internal state based on rationality. In this model, since the target's internal state is directly expressed by its behavior, the agent can adjust its own internal state based on rationality without estimating the target's internal state.

CCS CONCEPTS

• **Human-centered computing → Interaction design**; *User models*;

KEYWORDS

Initial phase of communication; spatial interaction; agent-based model

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1 INTRODUCTION

For artifacts such as robots that communicate with humans in real space, behaviors must be implemented that adjust whether to start communication with them since the initial phase of communication between humans is based on such body expressions as distance, body direction, and gaze and facial expressions [11, 12]. Communication's initial phase is a shift from an unfocused interaction where scant attention is paid to each other to a focused interaction where attention is directed to each other [6]. Implementing communication's initial phase with artifacts must be simplified so that artifacts can start conversations with people who want to communicate and to refrain from interfering with those who are not interested.

This research investigates how to represent preferences for relationships with others as internal agent states and how to generate agent-spacing behavior from its internal state to design agent behavior in the initial phase of communication. The messages of human communication include the aspects of relationships with a partner [19]. In encounter scenes, humans send signals that convey whether they want to engage with partners through nonverbal behavior. Thus, the preference for relationships with others is suitable for the internal state that the agent should exhibit in the initial phase of communication. In social interaction between humans and agents, robots need to present readable social cues that humans can easily understand to provide feedback about their internal states [4]. Since communication rarely occurs unless an agent approaches another agent, the presence or absence of preferences about involvement with others can be directly exhibited by such spacing behavior as approaching and evading. In addition, humans adjust their distance and body direction based on their relationships with others [1, 7]. Thus, spacing behaviors are critical to exhibit internal states in communication's initial phase.

Since robots spacing behaviors also affect the initial phase of communication with humans, to design approaching behavior and evading behavior are necessary. In Human-Robot interaction research on the initial phase of interaction, the timing to start moving or speaking from the participant's trajectory and gaze direction is estimated, and the robots starting communication with participants are implemented [5, 8, 14, 15]. The distance and approaching direction of the robot affects humans' feelings of preference and comfort toward the robot [2, 18]. Based on the spacing behavior of humans, some HRI studies generate socially acceptable approaching path of the robot [9, 17]. The spacing behavior in starting communication between humans is applicable to designing of robot behavior. Depending on the trajectory when the robot evades humans, The humans feeling of comfort is different [13]. Based on these researches, avoidance path generation of robots taking account for social distance is carried out [3, 16]. For each of the scenes that need to talk to people or the scenes that need to avoid people, it is possible to design appropriate behaviors of robots for humans.

Although it is possible to generate spacing behavior appropriate for each situation in which the agent approach humans or in which

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the agent avoid humans, it is not clear how to construct these situations. It is necessary for agents to express the internal state that the agents want to involve human and to judge whether the human can accept it.

In this study, we propose an agent model that possesses relationship preferences with its partners as an internal state and generates spacing behavior based on its internal state and the relative position with a partner. In this model, the involvement of two directions is deemed the relationship preferences: control as a preference of aggressive involvement to the partner and acceptance as the preference of passive involvement from the partner. The model associates the intensity of aggressive and passive involvements based on the relative distance and the relative angle of the partner. With this information, the model's agent changes its relative position to the partner by behavior based on the value of its internal state. The model considers the movement of a two-dimensional plane and body orientation as spacing behavior.

In this study, we investigated the interactions caused by combinations of the internal states of two agents through computer simulation. The proposed model's agent generated behavior to a target in virtual space. The trajectories of approach or evading behavior, generated based on the value of the agent's internal state, are shown and compared. By analyzing the generated behavior, we identified the effect of combinations on the interaction of the internal states of two pairs of agents. For the agent, the combinations of the internal states simplified reaching its preferred position and clarified the position combinations that became unreachable. Based on this result, we considered the changes of the internal state based on rationality.

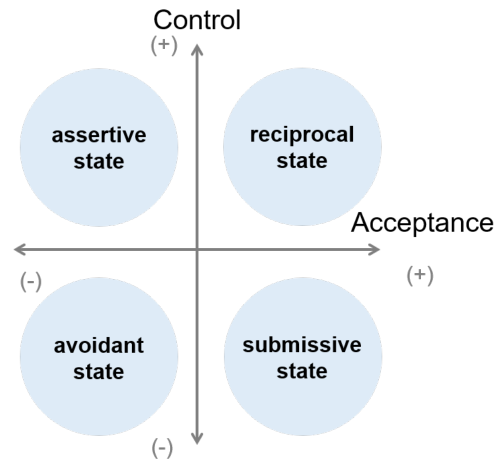

Figure 1: Internal state of model

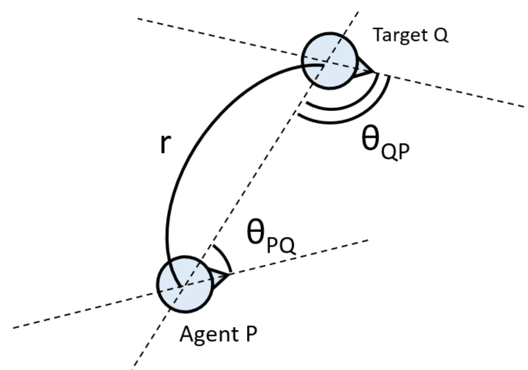

Figure 2: Physical features

2 MODEL

In this section, we describe an agent model that represents spatial interactions during encounters. The agent is an entity that improves a situation based on its preferences, which are represented by internal states. The agent behavior is represented by a change in its own position and determined by its internal state and its positional relationship with the target. Below we describe the setting of the agent's internal state and a method that determines its behavior.

2.1 Internal states

The agent has preferences for a relationship with an object and expresses them as an internal state. This model considers two relationship preferences with a target: control and acceptance. Control represents a positive or negative preference of aggressive involvement with the target. Acceptance represents a positive or negative preference of passive involvement from the target. The agent in this study has one of four internal states, which are positive and negative combinations of these two preferences (Fig. 1). Thus, its internal state z takes one of the following values:

- $z = (+, -)$: assertive state in which an agent prefers aggressive involvement to a target;
- $z = (-, +)$: submissive state in which an agent prefers passive involvement from a target;
- $z = (+, +)$: reciprocal state in which an agent prefers mutual involvement with a target;
- $z = (-, -)$: avoidant state in which an agent prefers no involvement with a target.

Using the agent's internal state z, the control value is obtained by $c(z)$, and the acceptance value is obtained by $a(z)$.

2.2 Physical features and involvement

By moving the position of the two-dimensional plane and the rotating body direction, the agent can change the intensity of its aggressive and passive involvements determined by its spatial relationship with the target. As shown in Fig. 2, the spatial relationship between agent P and target Q is represented by three parameters: distance r, relative angle θ_{PQ} seen from P, and relative angle θ_{QP} seen from Q. The transactional segment in which a human is involved with a target has a short distance and a front direction [10]. The intensity of the involvement increases when the distance and relative angle decrease; the intensity decreases when the distance and the relative angle increase.

2.3 Behavior

Both the control and acceptance values affect the behavior of agents and change the distance to the target since both aggressive and passive involvement can occur by shortening the distance to the target. When the sum of the control and acceptance values is positive, the agent decreases its distance to the target. When the sum is negative, it increases the distance. Thus, distance direction component $\Delta_P r$ of the agent's positional moving is obtained:

$$\Delta_P r = -\operatorname{sgn}(c(z) + a(z))\, v_{dis}(z, r_{PQ}). \tag{1}$$

where v_{dis} is a function that determines the magnitude of the distance direction component.

The component perpendicular to $\Delta_P r$ represents the agent's movement around the target. Passive involvement from the target arises because the agent is positioned in front of the target. When the acceptance value is positive, the agent moves around in front of the target as decreasing $|\theta_{QP}|$. When the acceptance value is negative, the agent circumvents the front of the target as increasing $|\theta_{QP}|$. Thus, revolutional direction component $\Delta_P \theta_{QP}$ of the agent's positional moving is obtained:

$$\Delta_P \theta_{QP} = \begin{cases} -\operatorname{sgn}\left(a(z)\theta_{QP}\right) v_{rot}(z, \theta_{QP}) & \text{if } \theta_{QP} \neq 0 \\ -\operatorname{sgn}\left(a(z)\right) v_{rot}(z, \theta_{QP}) & \text{if } \theta_{QP} = 0 \end{cases}, \tag{2}$$

where v_{rot} is a function that determines the magnitude of the revolutional direction component.

Independently of the positional movement, the agent can turn its body direction. Aggressive involvement to the target arises when the target is positioned in front of the agent. When the control value is positive, the agent turns its body direction to the target as decreasing $|\theta_{PQ}|$. When the control value is negative, the agent turns its body direction away from the target as increasing $|\theta_{PQ}|$. Thus, body turn $\Delta_P \theta_{PQ}$ of the agent is obtained:

$$\Delta_P \theta_{PQ} = \begin{cases} -\operatorname{sgn}\left(c(z)\theta_{PQ}\right) v_{turn}(z, \theta_{PQ}) & \text{if } \theta_{PQ} \neq 0 \\ -\operatorname{sgn}\left(c(z)\right) v_{turn}(z, \theta_{PQ}) & \text{if } \theta_{PQ} = 0 \end{cases}, \tag{3}$$

where v_{turn} is a function that determines the magnitude of body turn.

3 SIMULATION EXPERIMENT

In this experiment, we set the agent's internal state and simulated its behavior on a two-dimensional virtual plane to compare the trajectories drawn by the agents for each internal state. In addition, we evaluated the interaction between them and their behavior that is based on their internal states.

3.1 Agent's internal state

For simplicity, the agent's internal state in this simulation is limited to a value on a circle with a radius of one on the two-dimensional coordinates of control–acceptance as shown in figure 3. The control and acceptance values are obtained by angular coordinate ψ_z of the internal state:

$$c(z) = sin(\psi_z), \tag{4}$$

$$a(z) = cos(\psi_z). \tag{5}$$

The agent behaviors are generated for all 24 conditions with different values of ψ_z. In particular, we simulated the agent's behavior

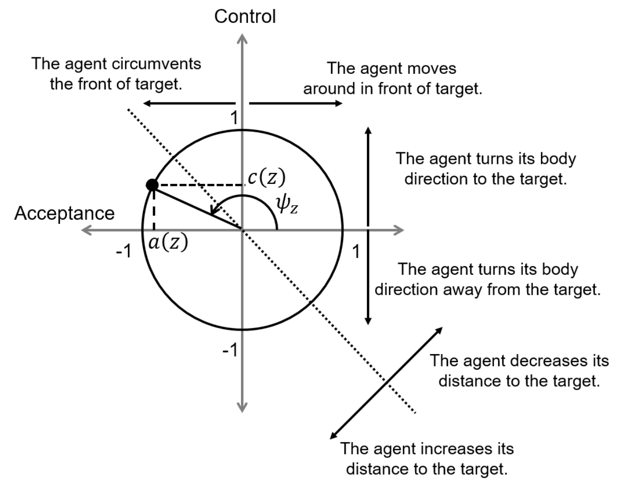

Figure 3: Angular coordinate ψ_z of the agent's internal state.

when its internal state takes each element of Ψ_z:

$$\Psi_z = \{180 - 15n | n \in \mathbb{Z}, 1 \leq n \leq 24\} \tag{6}$$

3.2 Agent behavior

Because the agent moves at a constant speed when it changes position, $v_{dis}(z, r)$ and $v_{rot}(z, \theta_{QP})$ are set so that $\sqrt{\Delta_P r^2 + \Delta_P \theta_{QP}^2} = 1$. $v_{dis}(z, r)$ is obtained by the following equation:

$$v_{dis}(z, r) = \begin{cases} 0 & \text{if } r \leq r_{min}, c(z) + a(z) > 0 \\ \cos(\arctan \frac{2a(z)}{c(z)+a(z)}) & \text{otherwise} \end{cases}, \tag{7}$$

where r_{min} is the minimum distance of the agent who is approaching the target (in this case, 60 pixels). $v_{rot}(z, \theta_{QP})$ is obtained by the following equation:

$$v_{rot}(z, \theta_{QP}) = \begin{cases} 0 & \text{if } |\theta_{PQ}| \leq \theta_{min}, a(z) > 0 \\ \sin(\arctan \frac{2a(z)}{c(z)+a(z)}) & \text{otherwise} \end{cases}, \tag{8}$$

where θ_{min} is a minimum angle that the agent shortens (in this case, 1°).

When $|\theta_{PQ}| \leq \theta_{min}$, the agent considers the distance direction component of the positional movement. From Eq. (1), $\Delta_P r$ is the value of $v_{dis}(z, r)$, obtained by the following only when $|\theta_{PQ}| \leq \theta_{min}$ and $a(z) > 0$:

$$\Delta_P r = \begin{cases} 0 & \text{if } r \leq r_{min}, c(z) + a(z) > 0 \\ 1 & \text{otherwise} \end{cases} \tag{9}$$

When $r \leq r_{min}$, the agent considers the revolutional direction component of a positional movement. From Eq. (2), $\Delta_P \theta_{QP}$ is the value of $v_{rot}(z, \theta_{QP})$. However, $\Delta_P \theta_{QP}$ is obtained by the following only when $r \leq r_{min}$ and $c(z) + a(z) > 0$:

$$\Delta_P \theta_{QP} = \begin{cases} 0 & \text{if } |\theta_{QP}| \leq \theta_{min}, a(z) > 0 \\ 1\,(c(z)) & \text{otherwise} \end{cases} \tag{10}$$

Since v_{turn} is independent of $v_{dis}(z, r)$ and $v_{rot}(z, \theta_{QP})$, it takes a constant value based on the values of ψ_z , θ_{PQ} . $v_{turn}(z, \theta_{PQ})$ is obtained by the following equation:

$$v_{turn}(z, \theta_{PQ}) = \begin{cases} 0 & \text{if } |\theta_{PQ}| \leq \theta_{min}, c(z) > 0 \\ 1 & \text{otherwise} \end{cases}. \tag{11}$$

3.3 Settings

The environment is 4000 x 4000 squared pixels. The target's initial position is the center of the field ($x = 2000, y = 2000$), and the body direction is 90°. The agent's initial position is r , where θ_{QP} and θ_{PQ} of the spatial relationship with the target are 150 pixels, 45° and 45°, respectively. The agent moves 2000 steps in each condition. When r reaches 600 pixels, the interaction between the agent and the target is broken, and the agent stops. We conducted two simulation phases. In first, we only investigated the agent's behavior. Thus, the target does not move from its initial position. In the second simulation stage, we investigated the interaction caused by the combination of an agent whose internal state is ψ_z^i and a target whose internal state is ψ_z^j. Thus, the target also moves as an agent of the model. In particular, $\psi_z^i, \psi_z^j \in \Psi_z$, and all combinations are simulated.

3.4 Evaluation

We investigated the trajectory of the agent movement in each internal state. The agent approaches the target when $c(z) + a(z) > 0$ and evades it when $c(z) + a(z) < 0$. Depending on the values of $c(z)$ and $a(z)$, the agent trajectory is rectilinear or curved. When $c(z) + a(z) < 0$, the agent goes around the target while maintaining its distance. By plotting the trajectories generated by the simulation, we compared the agent behaviors that depend on the internal state and evaluated the agent's interaction with the target when it moves as an agent of the model. We evaluated the interaction by comparing the movement toward the stationary target. The baseline for evaluating the agent's interaction with a moving target is its behavior with the same internal state value toward the stationary target. When the agent with internal state ψ_z^i moves toward the stationary target, the relative position in a step is represented by $(r^i, \theta_{QP}^i, \theta_{PQ}^i)$. When agent i with internal state ψ_z^i interacts with target j with internal state ψ_z^j, the relative position in a step is represented by $(r^{ij}, \theta_{QP}^{ij}, \theta_{PQ}^{ij})$. In the interaction with agent i and target j, evaluation value α_{dis} is the distance direction component of agent i's positional movement, obtained as follows:

$$g_{dis} = \begin{cases} |r^{ij} - r_{min}| - |r^i - r_{min}| & \text{if } c(z_i) + a(z_i) > 0 \\ 0 & \text{if } c(z_i) + a(z_i) = 0 \\ |r^{ij} - r_{max}| - |r^i - r_{max}| & \text{if } c(z_i) + a(z_i) < 0 \end{cases} \tag{12}$$

Evaluation value α_{rot} to the revolutional direction component of agent i's positional movement is obtained:

$$g_{rot} = \begin{cases} \cos(\theta_{QP}^i - \theta_{min}) - \cos(\theta_{QP}^{ij} - \theta_{min}) & \text{if } a(z_i) > 0 \\ 0 & \text{if } a(z_i) = 0 \\ \cos(\theta_{QP}^i - \theta_{max}) - \cos(\theta_{QP}^{ij} - \theta_{max}) & \text{if } a(z_i) < 0 \end{cases} \tag{13}$$

Evaluation value α_{turn} to the body turn of agent i is obtained:

$$g_{turn} = \begin{cases} \cos(\theta_{PQ}^i - \theta_{min}) - \cos(\theta_{PQ}^{ij} - \theta_{min}) & \text{if } c(z_i) > 0 \\ 0 & \text{if } c(z_i) = 0 \\ \cos(\theta_{PQ}^i - \theta_{max}) - \cos(\theta_{PQ}^{ij} - \theta_{max}) & \text{if } c(z_i) < 0 \end{cases} \tag{14}$$

The evaluation steps are the 1st, the 200th, and the final step (in this case, the 2000th step).

4 SIMULATION RESULTS

4.1 Trajectories

The trajectories of the agent behavior (Figs. 4, 5, and 6) are shown in three internal states: approaching, evading, and maintaining distance with the stationary target. The triangles, which represent the agent's position and orientation, are colored as the number of steps increase. The red triangles represent the agent's trajectory in the assertive state, the blue triangles are the submissive state, the purple triangles are the reciprocal state, and the gray triangles are the avoidant state. Note that the magnification of the field to be plotted and the intervals of the steps to plot the triangles are different in each figure. In both the approaching and evading behaviors, trajectories with different curvatures were generated depending on ϕ_z (i.e., the control and acceptance values).

Figure 7 shows examples of the interaction between an agent that is evading an approaching target. The internal states of agents ψ_z^i were -120, -90, -60, and 150 (upper left, upper right, lower left, and lower right, respectively). Target internal state ψ_z^j was 45 in each case. An agent whose revolution component of movement was zero (lower left) eluded the target to draw a straight line. Since the revolution component in the movement was large (upper left), the agent escaped from the target to draw a small circle trajectory. As shown in the lower right in Fig. 7, the agent's body angle kept the target direction while the agent evaded the target based on its positive control value.

4.2 Evaluation of interaction

Figure 8 shows evaluation values g_{dis} of the distance direction component of the agent's positional movements under all combinations of the conditions at the 1st, 200th, and 2000th steps (left, middle, and right, respectively). The elements of the matrix that combines the columns of internal state ψ_z^i of the agent and the rows of target internal state ψ_z^j indicate the value of g_{dis} of each condition. _dis becomes a positive value when the reaching degree to the preferred positional relationship through interaction is higher than when only the agent moves in the same number of elapsed steps and becomes a negative value when it is lower. The elements of the positive value are indicated by red cells, and the negatives are indicated by blue cells.

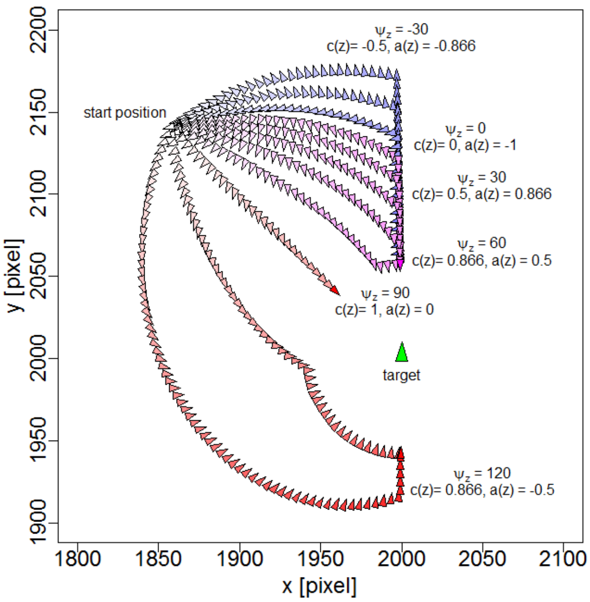

Figure 4: Trajectories of approaching agent: Triangles represent positions and directions every five steps. Depending on control and acceptance angles, curves with different curvatures were drawn.

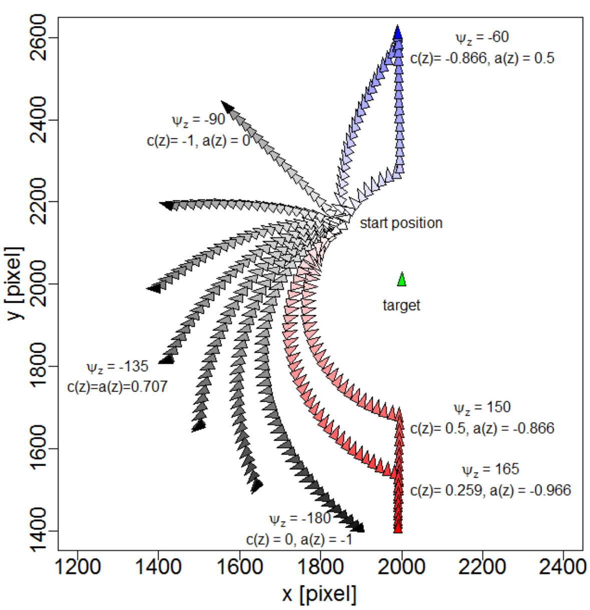

Figure 5: Trajectories of evading agent: Triangles represent positions and directions every 20 steps. Depending on control and acceptance values, curves with different curvatures were drawn.

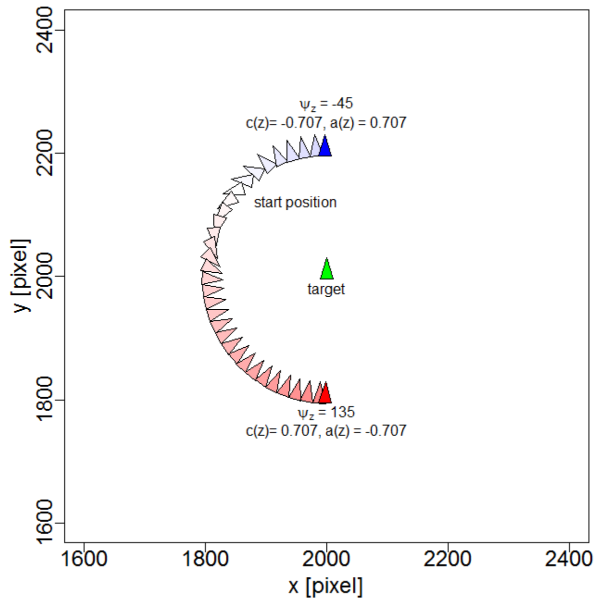

Figure 6: Trajectories of maintaining distance with target: Triangles represent positions and directions every 20 steps.

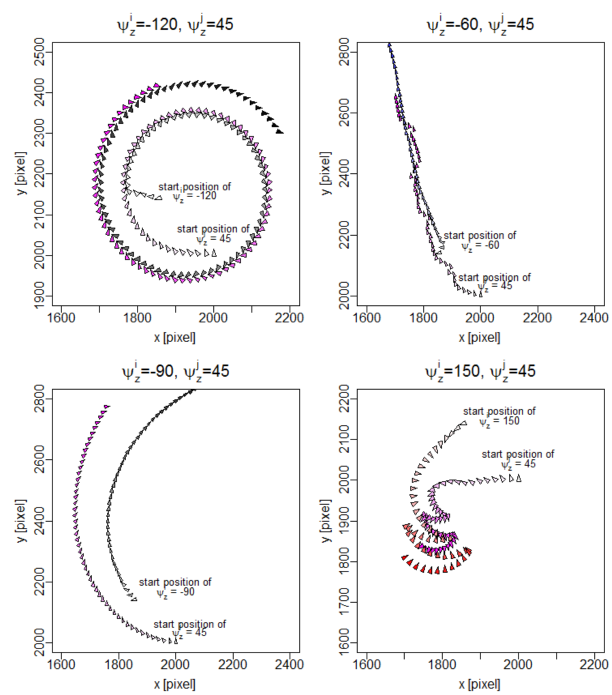

Figure 7: Trajectories of interactions between agent evading and approaching target. Various interactions occur depending on combinations of values of internal states.

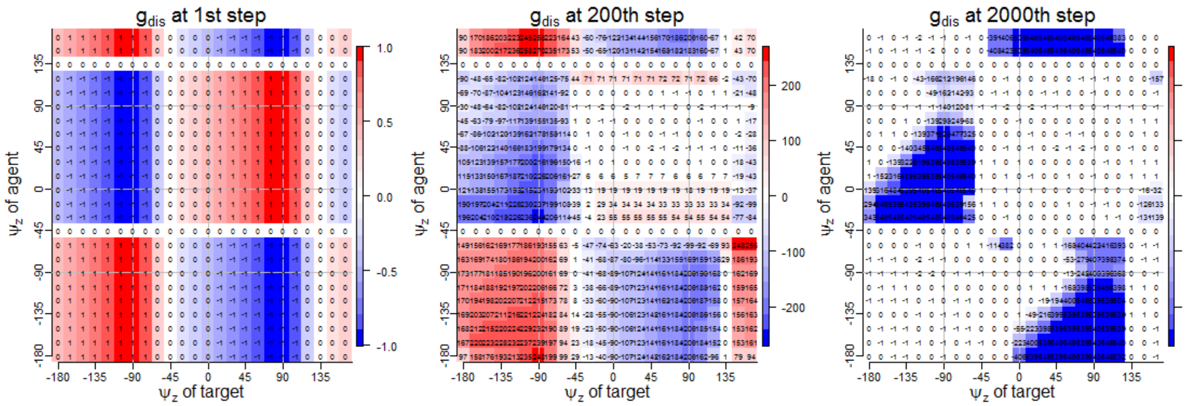

Figure 8: Matrix of distance evaluation value g_{dis} in each combination of internal states of agent and target: In left figure where preferences of agent and target matched, cells of combinations are red, and incongruous combinations are blue. In center and right figures, blue combinations show agent failed to reach referencing position.

The combinations in which g_{dis} in the first step was positive indicate that the target behavior benefits the agent, and conversely, the combination in which the value was negative indicates the target behavior hindered the agent. The combinations in which g_{dis} in the 2000th step was zero indicate that the agent reached the preferred distance with the target, and a negative indicates that the agent did not reach it. In the combination of avoidant–reciprocal and reciprocal–avoidant, evaluation value g_{dis} became smaller in many combinations. g_{dis} also became negative in most combinations of the approaching target and an agent whose $c(z)$ is positive despite evading the target. Regardless of the target's internal state, the condition where g_{dis} was small on average and approaching the target was the condition of $\psi_z^i = 90$ (i.e., the control value is positive and the acceptance value is zero). In the same way, the condition where g_{dis} is small on average and evading the target was the condition of $\psi_z^i = -90$ (i.e., the control value is negative and the acceptance value is zero).

Figure 9 shows evaluation values g_{rot} of the revolutional direction component of the agent's positional movement under all combinations of the conditions at the 1st, 200th, and 2000th steps (left, middle, and right, respectively). Fig. 10 shows evaluation values g_{turn} of the turn of the agent body direction under all combinations of the conditions at the 1st, 200th, and 2000th steps (left, middle, and right, respectively). As with g_{dis} , g_{rot} and g_{turn}, the first step indicated whether the target's behavior was beneficial or hindered the agent in the combination of its internal states. From Figs. 9 (left) and 10 (left), the number of combinations was equal where g_{rot} was positive, and the number of combinations where g_{rot} was positive and the number of combinations where g_{dis} is positive. However, to the right of Fig. 9, the number of combinations where g_{rot} became negative at the 2000th step exceeded the number of combinations where g_{dis} was negative. The right of Fig. 10 indicates that the number of combinations where g_{turn} became negative at the 2000th step was less than the number of combinations where g_{dis} was negative.

5 DISCUSSION

In this study, we proposed an agent model that generates spatial behavior depending on its relationship preference with a target. In a simulation experiment, we investigated agent behavior in a two-dimensional virtual environment based on various values of internal states and confirmed that the agent showed such behaviors as approaching, evading, or revolving, depending on the control and acceptance values. In addition, the interactions between the agent and the target moving based on the model were simulated. It was identified which combinations of agent and target were able to reach the agent preferred position and which combinations were not able to reach the position.

The interaction between agents and targets whose preferred positions match in the near position could transfer to the next phase of communication such as conversations. Conversely, the interaction between agents and targets whose preferred positions match in the far position could transfer to the end of the interaction, because they are no longer in the same space. The combinations shown in red in Figure 8–10 correspond to the above pairs that do not need to change their internal states.

In combinations that have discrepancies between the agent and target preferences shown in blue in Figure 8–10, it is rational for the agent to change its internal state. There are two types of changes in the internal state for an approaching agent: to change to the most efficient approaching state or to a not-moving state as resignation. Based on our simulation results, the most efficient internal state for approaching the target is one where the acceptance value is zero, and the agent approached linearly. It is efficient for the approaching agent to have a zero value as a component to revolve around the target. In this case, when the agent is approaching and the target is evading it, it is expected that the interaction will continue until either stops. When the agent stops approaching, the internal state is one in which both control and acceptance values are zero

There are two type of changes in the internal state for an evading agent: to change to the most efficient state for evading or to a state of involvement as resignation. Based on simulation results, the most efficient internal state for evading the target was also a state

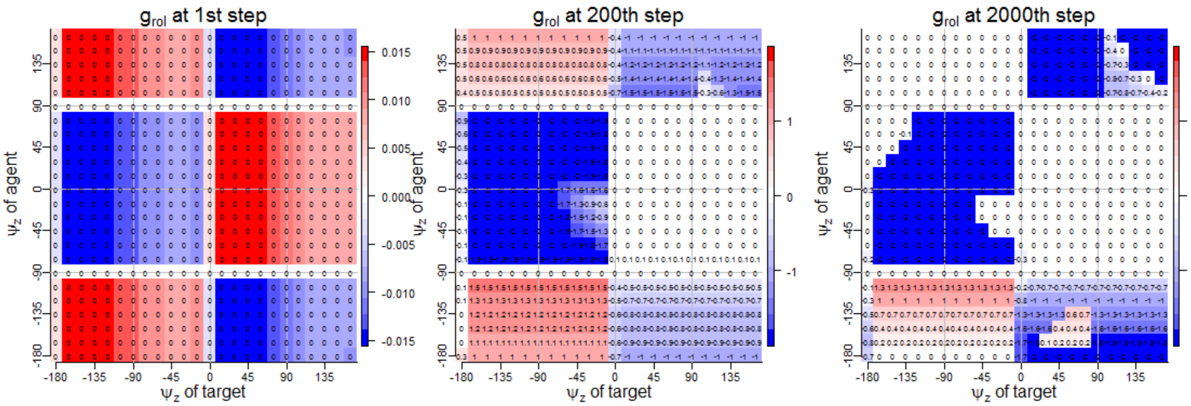

Figure 9: Matrix of rotational behavior evaluation value g_{rot} in each combination of internal states of agent and target

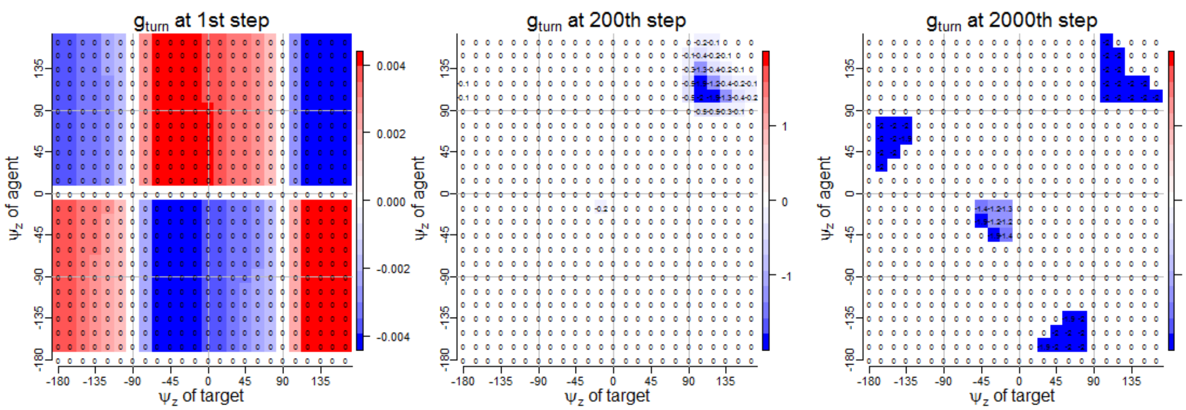

Figure 10: Matrix of turn evaluation value g_{turn} in each combination of internal states of agent and target

in which the acceptance value was zero. Therefore, an inverse relationship is expected in the above case of an approaching agent. When changing the internal state in a direction to compromise and start communication, the agent makes both the control and acceptance values positive

For the agent to create the above internal state transitions, it must be able to judge whether its own internal state matches the target's internal state. This judgment can be made by comparing the changes of the relative position only caused by its own motion and the relative position caused by the actual interaction with the method in the evaluation of interaction in this experiment. This method's advantage is that it can change its internal state due to the gap between the agent's behavior itself and the result without estimating the target's internal state, because the latter is directly revealed through behavior. However, a prerequisite for this method is that the target is aware of the agent's existence. At this stage the model does not consider the vision and the timing to notice the target. Due to this point, our future work will incorporate the internal state's change into our model.

6 CONCLUSION

We proposed an agent model that generates spatial behavior depending on its relationship preferences with its target. Our model incorporates two involvement directions: aggressive involvement to the target and passive involvement from the target. The agent model uses control and acceptance values as its internal state to represent the preferences of both aggressive and passive involvement. The model uses two-dimensional positional movement and its body direction's turn as agent spatial behaviors. The agent behavior for changing the distance with the target depends on both the control and acceptance values. The agent behavior for moving around its target depends on the acceptance value. The agent behavior for turning its body direction toward the target depends on the control value.

In our simulation experiment, we investigated the agent behavior in a two-dimensional virtual environment based on various internal state values. The simulation consisted of two situations: when the target did not move and when it moved identically as the agent. We confirmed that the agent showed such behaviors as approaching, evading, or revolving, depending on the control and acceptance values. In addition, combinations of the internal states of the agent and the target hastened reaching the position preferred by the agent, and inhibited combinations were identified. In this model, since the target's internal state is directly expressed by its behavior, the agent can adjust its own internal state based on rationality without estimating the target's internal state.

In this model, since the target's internal state is directly expressed by behavior, the agent can adjust its internal state itself based on rationality without estimating the target's internal state. Future work will incorporate the change of internal states into the model.

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