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Modeling of Animal Movement by AR process and Effect of Predictability of the Behavior on Perception of Animacy and Intentionality

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Abstract— **We perceive animacy even on a simple dot traveling across a screen based on its movements. Research studies have pointed out several features of movement that are assumed to induce the perception of animacy; however, validations and discussions about these features are still insufficient. Meanwhile, other studies indicate that the perception of the intentionality is a prerequisite for the perception of animacy but these perceptions have not been differentiated clearly in the literature. In this study, we conduct an experiment with human participants to clarify the differences between animacy and intentionality in terms of the predictability of behavior. First, we model the behavior of goldfish using an autoregressive process and create several types of movies of a white dot moving on a black background where we change the fluctuation levels of its velocity and its rotation. The movies are presented to human participants and they are asked to chase the white dot using a pen tablet so that the predictability of the behavior can be quantified. The participants are also asked to rate the animacy and the intentionality of the moving dot. Our results reveal a negative correlation between the perception of animacy and intentionality.**

I. INTRODUCTION

Which attributes of humanoid robots cause us to perceive humanity in them? How do animals distinguish the movement of their prey or predator from other movements of non living objects in the background? Even a moving dot on a screen can induce the perception of animacy in our minds; however, it is still unclear which features of the movement cause the perception. Meanwhile, some studies indicate that the perception of the intentionality is a prerequisite for perceiving animacy ([1][2][3][4][5]), but the two perceptions have not been differentiated clearly in the literature.

Several hypotheses have been put forward as factors in the perception of animacy for a moving object, such as self-propelled movement [6][7][8], violation of physical law [4], goal-directed movement [3], and accompanying movement [2]. The perception of intentionality is based on the observations of an activity with a goal. Goal-directed movement [3] and equifinality [9] aim for a specific outcome; therefore they usually suggest the presence of intentionality. On the other hand, these movements also tend to be self-propelled and to violate physical laws.

In this study, we propose objective predictability as a new measurement to inspect the degrees of and the relationship between the perception of animacy and intentionality. To measure the predictability of movements, we first modeled the behavior of goldfish using an autoregressive process, and created several types of movies featuring a white dot moving on a black background, where we changed the fluctuation levels of its velocity and its rotation. The movies were presented to human participants, who were asked to chase the white dot using a pen tablet, in order to quantify the predictability of the behavior. The participants were also asked to rate the animacy and the intentionality of the dot in the movies. Our study revealed the correlation among the predictability, the perception of animacy, and the perception of intentionality.

II. MODELING OF GOLDFISH MOVEMENT

In this study, we estimated objective predictability and the subjective psychological rating of the perception of both animacy and intentionality, using several types of movements of a dot on the screen. To obtain a wide range of results, we first tried to build a mathematical model of the movement of real goldfish, i.e. their changes of location. After we built the model of goldfish movement, we modeled the movements of various types of virtual animals by changing the parameters of the model for the experiment. Although a real goldfish occasionally stops swimming and rests for several seconds, we used only the parts of the data where the goldfish was swimming continuously, which was assumed to be a stochastically stationary process.

A. Animal

The goldfish used for data acquisition was a Carassius auratus var. Ryukin specimen with a body length of 50 mm, purchased from a local pet shop.

B. Environment for Video Capture

The movies of the goldfish movement were taken under an environment similar to Fig. 1. The size of the aquarium was $1,500mm \times 1,500mm$ and the water depth was approximately $50mm$. The aquarium was made of a wooden frame, and a white waterproof vinyl sheet was spread over the frame to privide a uniform background for the goldfish. A digital camera, Nikon COOLPIX S3100, was set at approximately $1,700mm$ above the water surface. Two lights were also set above the water.

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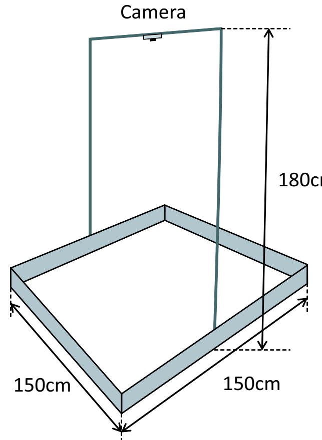
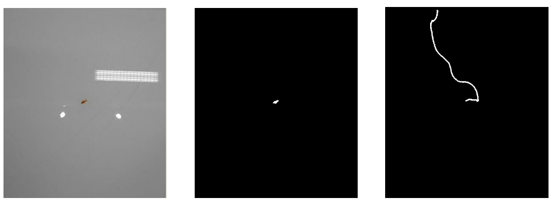


Fig. 1. Environment used for video capture



(a) Before image processing (b) Extraction of goldfish location (c) A trajectory of goldfish movement

Fig. 2. Image processing steps

C. Data Acquisition

The movies were captured in the AVI format at 30 fps, with a resolution of 640 × 480. Eight 30-min movies were taken. From the 240-min footage, we removed stochastically unstationary process parts such as when the goldfish was resting, swimming along the wall, or initial relatively active motion, and we were left with 22 movie segments. Using OpenCV, a library of programming functions for real-time computer vision, we extracted the two-dimensional location of the goldfish from each frame. The location was calculated as the center of mass of the goldfish.

D. Modeling the Goldfish Movement using the Autoregressive Process

We developed a mathematical model for the time series of the two-dimentional data (the location changes of the goldfish), using the autoregressive (AR) model. The AR model is defined as:

$$x(t) = c + \sum_{i=1}^{p} a_i x(t-i) + \epsilon_t$$

Here, t is a descreat time, c is constant, $a_1, \cdots, a_p$ are parameters of the model, where p is the dimension of the model, and ϵ_t is the i.i.d Gaussian additive noise.

To apply the AR model, the two-dimensional location data $x(t) \in \mathbb{R}^2$ was transformed to $(v(t), \phi(t))^T \in \mathbb{R}^2$ as follows:

$$\begin{aligned} x(t+1) &= x(t) + \Delta x(t) \\ \Delta x(t) &= v(t) L(\phi(t)) \frac{\Delta x(t-1)}{|\Delta x(t-1)|}. \end{aligned}$$

Here, $v(t)$ is the velocity and $\phi(t)$ is the rotation of the head at time t, and L is the rotation operator. After we confirmed that the histograms of both $v(t)$ and $\phi(t)$ were close to the normal distribution, the parameters of the AR model for each time series were estimated using the Yule-Walker and Levinson-Durbin algorithms. Each order of the model was determined using the values of Akaike's information criterion (AIC). The mean values of $v(t)$, originally measured as pixels per frame, were normalized, so that the mean and the standard deviation of $v(t)$ became 1.0 and 0.3484, respectively. The model has the smallest AIC (0.1791) when $p = 156$. When $p = 57$, the mean and standard deviation of the rotation (radian) were 0.01 and 0.1724, respectively, and the model had a minimum AIC of 0.0250. Although the dimensions for the model might be reduced by dropping down the number of frames per second of the movie, we used the additional frames to smooth out the movements.

E. Making Movies for Experiments

From the mathematical model of the goldfish movement, we modeled the movements of several types of virtual animated objects by adjusting the parameters. To change the characteristics of the motion, we altered the standard deviations of $v(t)$ and $\phi(t)$ by integer multiplication of $\{0, 1, 2, 3\}$. The generated movements were described as follows:

$$\begin{aligned} x_{ij}(t+1) &= x_{ij}(t) + \Delta x_{ij}(t) \\ \Delta x_{ij}(t) &= i v(t) L(j\phi(t)) \frac{\Delta x(t-1)}{|\Delta x(t-1)|} \\ i, j &= \{0, 1, 2, 3\} \end{aligned}$$

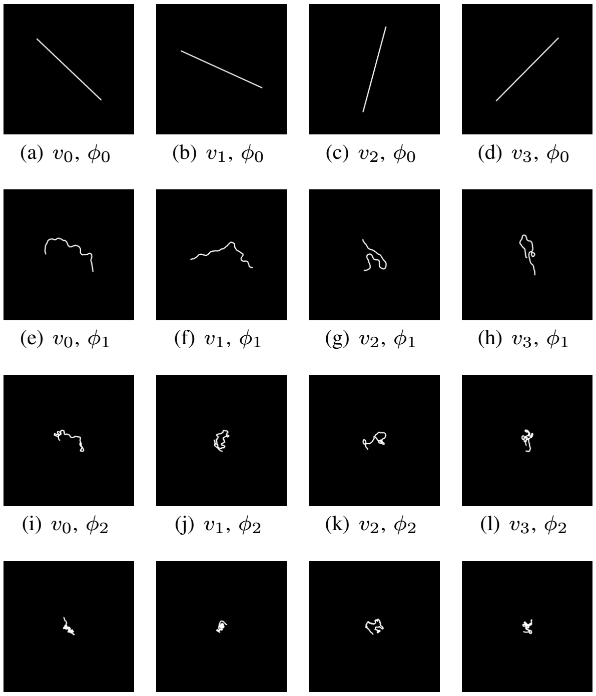
The movement x_{11} corresponds to the reproduction of goldfish movement. The sample trajectory of each generated movement is shown in Fig. 3.

III. EXPERIMENT

Each experiment for each movie consisted of three parts: (1) a task to trace the moving dot to estimate predictability; (2) a questionnaire to rate the psychological perception of animacy; (3) a questionnaire to rate the psychological perception of intentionality. Seventeen different movies were randomly displayed on a computer screen for each participant. For each test subject, this experiment measured two factors with four levels each.

A. Stimuli

We prepared the 16 generated movies and an original location-transition movie of the goldfish. Because goldfish movements are slow and because it is difficult to obtain enough values to calculate the index of predictability, the playback speed of all the movies were adjusted to 5.0×. In each movie, a white moving dot is displayed on a uniform black background. The subjects were not informed about how the movies were made. The seventeen movies were randomly presented to each participant.



(a) v_0, ϕ_0 (b) v_1, ϕ_0 (c) v_2, ϕ_0 (d) v_3, ϕ_0

(e) v_0, ϕ_1 (f) v_1, ϕ_1 (g) v_2, ϕ_1 (h) v_3, ϕ_1

(i) v_0, ϕ_2 (j) v_1, ϕ_2 (k) v_2, ϕ_2 (l) v_3, ϕ_2

(m) v_0,ϕ_3 (n) v_1, ϕ_3 (o) v_2, ϕ_3 (p) v_3, ϕ_3

Fig. 3. Sixteen trajectories used as visual stimuli

Fig. 4. Schematic diagram of experimental apparatus

B. Object Tracking

In the object-tracking experiments, the subjects were instructed to track a moving white dot in each of the 17 movies using a pen tablet. A schematic diagram of the experimental apparatus is shown in Fig.4. The subjects were required to look at a display and to follow a moving 4-pixel white dot with a 3-pixel red dot on the same display. The red dot is controlled using the pen tablet. Although the trajectory is shown in Fig.4 for ease of explanation, no trajectories were shown in the experiments. To quantify the predictability of the trajectory, mean values of Euclidean norm between the white dot and the red dot were calculated.

C. Questionnaire

After each object-tracking experiment, participants were asked to answer questions about the animacy and intentionality, using following 7-point Likert scale: 1-Strongly disagree, 2-Disagree, 3-Somewhat disagree, 4-Neither agree or disagree, 5-Somewhat agree, 6-Agree, 7-Strongly agree.

D. Participants

Seventeen undergraduate students (10 males, 7 females) participated in the experiment.

IV. RESULTS AND DISCUSSION

Figure 5 shows the effects of the variances of both angle change and velocity change on the predictability. The higher the predictability value, the more difficult the prediction is. A two-way analysis of variance (ANOVA) showed that the variance in angle change significantly affected predictability $[F(3,\ 240) = 12.59, p < 0.01]$, whereas the variance in velocity change did not significantly affect predictability $[F(3,\ 240) = 0.40, p = 0.75]$. We could not confirm how the variance in angle change and the variance in velocity change $[F(9,\ 240) = 0.63, p = 0.77]$ affected predictability. The main reason might be that the movement of real goldfish had relatively little velocity change, so the fluctuation of the velocity was also insignificant even when its scale was increased. With no rotation change (0×), the movement becomes linear and the prediction becomes easy. Predictability also becomes relatively easier as the variance of rotation becomes large (3×), probably because the dot tends to move in a relatively small area.

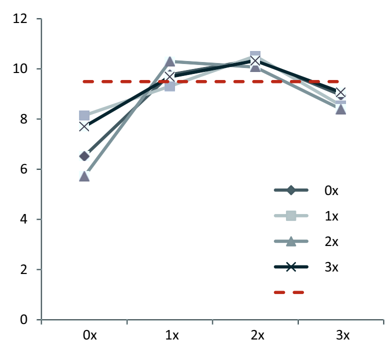


Fig. 5. Features of moving dot and predictability

Figure 6 shows the mean values of the ratings for the perception of animacy for the 17 movies. The variance in rotation significantly affected the perception of animacy $[F(3, 240) = 34.02,\ p < 0.01]$. On the other hand, the velocity change did not significantly affect the perception of animacy $[F(3, 240) = 0.16,\ p = 0.92]$. We could not confirm how the variance of angle change and the variance of velocity change $[F(9, 240) = 0.48,\ p = 0.90]$ affected on the perception of animacy.

This result is similar to that of objective predictability (Fig.5). The relationship between objective predictability and the perception of animacy is shown in Fig.8(a) as a scattargram. The correlation coefficient of predictability and animacy was strong at 0.79 ($p < 0.01$). This relation suggests that predictability is a significant factor in the perception of animacy.

The effect of the features of the moving dot on the perception of intentionality is shown in Fig.7. Although the effect of the variance of rotation on the perception of intentionality

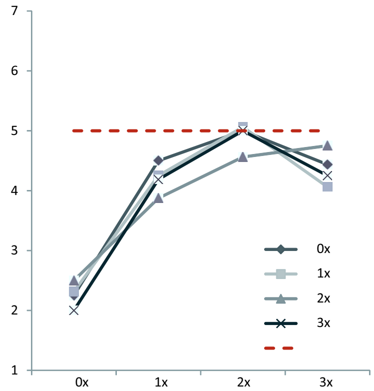


Fig. 6. Features of moving dot and animacy rating

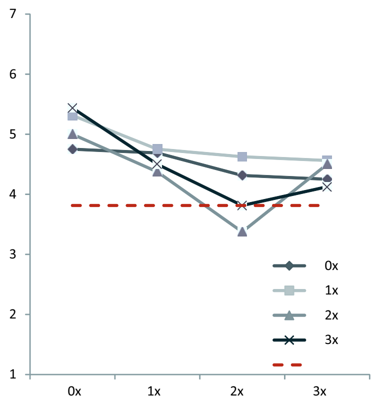


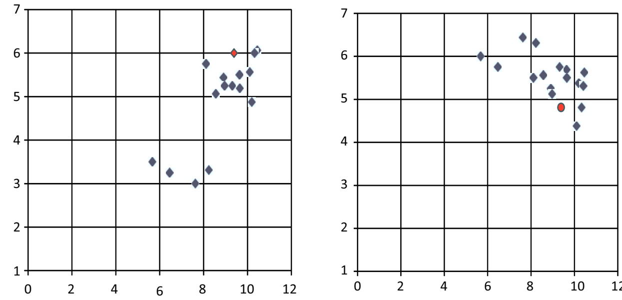
Fig. 7. Features of moving dot and intentionality rating

was significant $[F(3, 240) = 4.97,\ p < 0.01]$, that of velocity change was not significant $[F(3, 240) = 1.03,\ p = 0.38]$. We could not confirm any interaction between the effect of variance of rotation and that of velocity change $[F(9, 240) = 0.58,\ p = 0.81]$. The intentionality rating differs from the animacy rating significantly (Figs. 7 and Fig. 6). The intentionality rating has maximum values when the movement has no rotation. As shown in the scattargram of Fig. 8(b), the correlation coefficient of predictability and intentionality was -0.58 ($p < 0.05$). This result contradicts the generally accepted idea that the perception of intentionality is a prerequisite for the perception of animacy.

A possible reason why participants sensed intentionality on a linearly moving dot (Fig. 7 $0\times$) is that humans strongly perceive the intentionality if they already perceive animacy on the object.

V. CONCLUSIONS

The purpose of this study was to investigate the perception of animacy and that of intentionality from the viewpoint of objective predictability. The predictability was estimated by tracking a moving dot on a display using a pen tablet. To make the dot movement animate enough, we modeled the movement of a real goldfish using AR process. Using several types of dot movements, the experiments revealed that, as the predictability of the dot movement becomes difficult, the



(a) Scattergram of objective predictability and animacy rating (b) Scattergram of objective predictability and intentionality rating

Fig. 8. Relation between predictability, perception of animacy and intentionality

perception of animacy becomes stronger, but the perception of intentionality becomes weak. These results contradict previous explanations that the perception of intentionality is a prerequisite for the perception of animacy.

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