The Fourteenth International Symposium on Artificial Life and Robotics 2009 (AROB 14th '09),
B-Con Plaza, Beppu, Oita, Japan, February 5 - 7, 2009

An abstract model for investigating the adaptivity of misperception

Jin Akaishi

Department of Information and Electronic Engineering, Yatsushiro National College of Technology,
2627 Hirayama-Shin-Machi, Yatsushiro, Kumamoto 866-8501, Japan
akaishi@as.yatsushiro-nct.ac.jp

Takaya Arita

Graduate School of Information Science, Nagoya University,
Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan
arita@nagoya-u.jp

***Abstract*: We have been focusing on the adaptive property of misperception. Our hypothesis is that misperception can be adaptive because of its beneficial function of increasing diversity in population by reducing the majority bias of collective behavior. In our previous studies, we constructed a simple agent-based model in which agents perform a foraging task. The simulation results showed that misperception could increase diversity in behavior of agents, thus could be adaptive. This paper investigates on the general conditions for misperception to be adaptive based on these preliminary results. For this purpose, we use a mathematical model that does not depend on specific tasks. More specifically, we construct an abstract model in which each agent selects a behavioral choice depending on the rewards for the choices and then obtains a reward based on the distribution of selected behaviors by all agents involved. We evaluate the adaptive property of misperception by considering the balance among environments, cognition and behavior in terms of entropy. It has been shown quantitatively that misperception becomes adaptive by diversifying the distribution of collective perception when agents adopt a behavioral strategy that tends to show overmatching, which decreases the entropy of behavior compared with the entropy of the rewards in environments.**

***Keywords*: Misperception, Diversity, Adaptivity.**

I. INTRODUCTION

Fretwell and Lucas proposed the Ideal Free Distribution (IFD) theory which predicts that individual animals will aggregate in various patches proportionately to the amount of resources available in each [1]. Since then empirical studies have confirmed a tendency toward the IFD in a number of species. In more general context, some studies pointed out a possibility that diversity in collective behavior is autonomously adjusted universally at various levels such as reasoning or communication/language, when fitness contribution of a behavior conducted by an individual of social animals or insects depends on the distribution of their behavior in population [2][3].

However, we can easily imagine situations in human societies where IFD does not hold true. Especially, there is a tendency that a behavior which seems to obtain the best reward is chosen intensively. For instance, if every car driver trusts a source of information on traffic conditions, new traffic jams might be caused as a result. Also, if an information impels many investors to buy a specific stock, many of them might finally have poor profits or suffer a loss owing to the convergence.

We have been focusing on the role of misperception, in other words, the noise at the level of cognition. Our hypothesis is that misperception is adaptive under such circumstances because of its beneficial function of increasing diversity in population by reducing the majority bias of collective behavior. So as to test this hypothesis, we constructed a simple agent-based model in which agents perform a foraging task in our first study. The simulation results showed quantitatively that misperception could increase diversity in behavior of agents, thus could be adaptive, while accurate communication could decrease a diversity of agent behavior, which might decrease fitness. We also discussed the relationship between direct misperception and indirect misperception. Furthermore, we showed that behavioral specificity has dominant effects on adaptive property of misperception [4][5].

We extended the model by introducing the evolution of misperception partly from the evolutionary psychology perspective in our second study. The results showed that while keeping the general tendency towards optimal values, uneven distribution of food resources causes a difference between adaptivity at population level and at individual level, which produces a selection pressure toward lower misperception rates [6]. Also, Brumley and others have recently conducted a related study inspired by our first study [7].

This paper investigates on the general conditions for misperception to be adaptive based on these preliminary results. For this purpose, we use a mathematical model that does not depend on specific tasks. More specifically, we construct an abstract model in which each agent selects a behavioral choice depending on the rewards for the choices and then obtains a reward based on the distribution of selected behaviors by all agents involved. We evaluate the adaptive property of misperception by considering the balance among environments, cognition and behavior in terms of entropy.

II. MODEL

In this model (Fig. 1), the environment provides agents with the pairs of a choice and a benefit, and each agent can obtain the corresponding reward by choosing one of the choices. We term distributions of benefits among all choices the distribution of reward. There are m choices, each of which is assigned a number c $(1 \le c \le m)$. The amount of the benefit of the choice c, *reward(c)* is decided by Eq. (1) being able to tune distributions by the parameter g. We define a vector consisting of *reward(c)* as **r.**

$$reward(c) = \frac{1}{1+e^{-g(c-m)}} \qquad (1)$$

There are n agents in the environment, each of which is assigned a number i $(1 \le i \le n)$. Agent i perceives a reward at a choice c as *perception*($\mathbf{r}$,i,c). There is a possibility that misperception occurs when an agent perceives a reward. The probability of misperception is defined as p_c. When agent i misperceives a reward, the agent perceives a reward for another choice (other than choice c as the reward for the

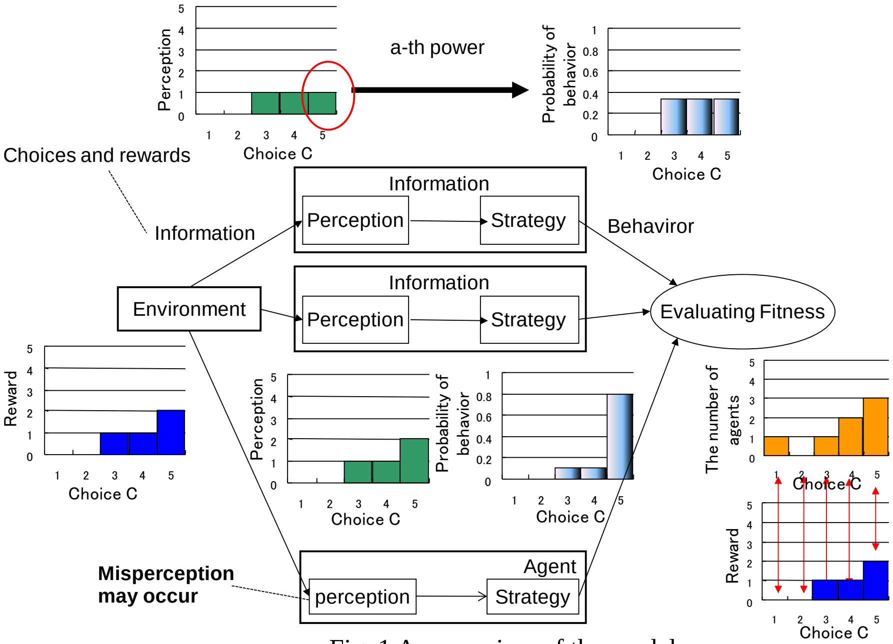

Fig. 1 An overview of the model.

choice c (Eq. (2)), which diversifies collective distributions of perception.

$$perception(\mathbf{r},i,c) = \begin{cases} reward(c) & \text{Prob. } 1-p_c \\ reward(\text{a choice except } c) & \text{Prob. } \frac{p_c}{m-1} \end{cases} \qquad (2)$$

We define a vector $\mathbf{p}(i)$ for agent i consisting of *perception*($\mathbf{r}$,i,c) of all choices. Each agent selects a choice based on *strategy*($\mathbf{p}(i)$,i,c) which is the behavioral probability with which agent i chooses the choice c (eq.(3)).

$$strategy(\mathbf{p}(i),i,c) = \frac{perception(\mathbf{r},i,c)^a}{\sum_{k=1}^{m} perception(\mathbf{r},i,k)^a} \qquad (3)$$

This probability is decided by the relative reward based on individual perceptions. The parameter a, which is common for all agents, adjusts the sensitivity to the distribution of the reward. The distribution corresponds to IFD when a is 1 and misperception does not happen.

A vector consisting of the behavioral probabilities of agent i is defined as $\mathbf{s}(i)$. The result of the choice of agent i is defined as *behavior*($\mathbf{s}(i)$,i,c) (eq. (4)).

$$behavior(\mathbf{s}(i),i,c) = \begin{cases} 1 & \text{if the agent choses } c \\ 0 & \text{otherwise} \end{cases} \qquad (4)$$

We evaluate fitness of the agents based on behaviors. The upper limit that an agent can gain a reward is determined by the total reward divided by the total number of the agents. Agents that chose a choice gain a reward that was equally divided by the number of the agents that chose the choice. Fitness of agent *i* is defined as $fitness_{ind}(B,\mathbf{r},i)$. $fitness_{ind}(B,\mathbf{r},i)$ is calculated by eq. (5), in which *B* is the matrix that consists of a vector **b**(i) of all agents and the vector **b**(i) consists of $behavior(\mathbf{s}(i),i,c)$.

$$fitness_{ind}(B,\mathbf{r},i) = \sum_{c=1}^{m}\left\{\min\left(\frac{reward(c)}{\sum_{d=1}^{m} reward(d)}\frac{behavior(\mathbf{s}(i),i,c)}{\sum_{j=1}^{n} behavior(\mathbf{s}(j),j,c)}, \frac{behavior(s(i),i,c)}{n}\right)\right\} \quad (5)$$

The function min(x, y) returns the smallest value in the arguments.

The distribution of rewards, the collective perception of agents and the distributions of behavioral probabilities are evaluated by calculating entropy. The entropy of the distribution of the reward H_{rew} is calculated based on *reward*(*c*) (Eq. (6)).

$$H_{rew} = -\sum_{c=1}^{m}\frac{reward\ (c)}{\sum_{d=1}^{m} reward\ (d)}\log_2\frac{reward\ (c)}{\sum_{d=1}^{m} reward\ (d)} \quad (6)$$

The entropy of the perception H_{perc} (Eq. (8)) is determined by mean perception $P_{perc}(c)$ (Eq. (7)), that is the average perception of all agents on each choice.

$$P_{perc}(c) = \frac{\sum_{i=i}^{n} perception\ (\mathbf{r},i,c)}{\sum_{d=1}^{m}\sum_{i=1}^{n} perception\ (\mathbf{r},i,d)} \quad (7)$$

$$H_{perc} = \sum_{c=0}^{m} P_{perc}(c)\log_2 P_{perc}(c) \quad (8)$$

The entropy of the strategy H_{str} (Eq. (10)) is determined by the mean behavioral probability $P_{str}(c)$ (Eq. (9)), that is the average behavioral probability of all agents on each choice.

$$P_{str}(c) = \frac{\sum_{i=1}^{n} strategy(\mathbf{p}(i), i, c)}{\sum_{d=1}^{m}\sum_{i=1}^{n} strategy(\mathbf{p}(i), i, d)} \quad (9)$$

$$H_{str} = -\sum_{c=1}^{m} P_{str}(c)\log_2 P_{str}(c) \quad (10)$$

III. RESULTS

We conducted simulation experiments based on the model to measure the effect of changing the distribution of rewards, strategy, and probability of misperception. The following parameters were used in these experiments: *n =1000, m =4 and a = 3*. H_{rew}, H_{perc} and H_{str} were normalized to the range between 0.0 and 1.0. The relative fitness is based on the fitness when the probability of misperception was 0.

The first results are shown in Fig. 2. The probability of misperception and distribution of rewards were changed in order to investigate the effect of misperception on fitness and the relation among fitness, H_{perc}, H_{str} and the difference between H_{rew} and H_{str}. P_{misp} in x-axis and H_{rew} in y-axis indicate the probability of misperception and the entropy of the rewards, respectively. The z-axis indicates the entropy of the perception H_{perc} in Fig. 2(a), the entropy of the strategy H_{str} in Fig. 2(b) and the absolute value of the difference between the distributions of the rewards and the strategy $|H_{str}-H_{rew}|$ in Fig. 2(c). The fitness in z-axis indicates the mean relative fitness for comparison of effects of misperception.

There was a general tendency that H_{perc} increased as H_{rew} or P_{misp} increased (Fig. 2(a)). Also, H_{str} (Fig. 2(b)) was smaller than H_{perc} (Fig. 2(a)) especially when H_{rew} was small. The results showed that agents were concentrated in choices with more rewards because the parameter *a* was larger than 1.0. In Fig. 2(c) there was a valley, indicating that the difference between H_{rew} and H_{str} was nearly zero, from $H_{rew} = 0$ and $P_{misp} = 0$ to $H_{rew} = 0.9$ and $P_{misp} = 0.4$. There was a peak of the fitness (Fig. 2(d)) along this valley. This means that the fitness was maximized when H_{str} coincides with H_{rew}. Hence, misperception increased H_{perc} and decreased the

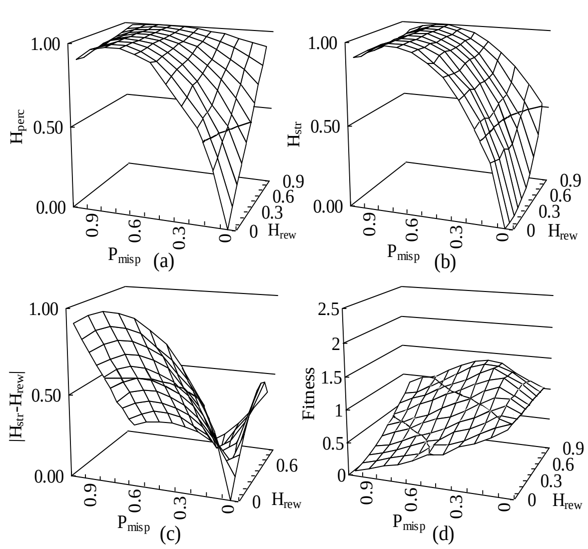

Fig. 2 (a) Entropy of perception, (b) Entropy of strategy, (c) Differences between the distributions of reward and strategy, (d) Fitness (*a*=3.0).

difference between H_{str} and H_{rew}. Fig. 2(d) shows that the higher H_{rew} was, the greater was the adaptive effect of misperception, which shows that the area in which misperception could be adaptive became larger as H_{rew} became higher.

Next, we investigated the effect of the strategy on fitness by changing the parameter of strategy a to be between 0.3 and 10.0 (Fig. 3). We see the area in which misperception is adaptive, that is fitness was greater than 1, tended to grow as the parameter a became greater. Especially, the adaptivity of misperception was not observed when the parameter a was less than or equal to 1.0 (Fig. 3(a) and Fig. 3(b)). We can presume that strategies causing high H_{str} decreased the gap between H_{str} and H_{rew}, and narrowed the range that misperception could diversify behavior. Therefore, misperception could be adaptive when there is the gap due to the concentration on specific choices.

We summarize the relations among misperception, strategy and fitness in Fig. 4, which illustrates the

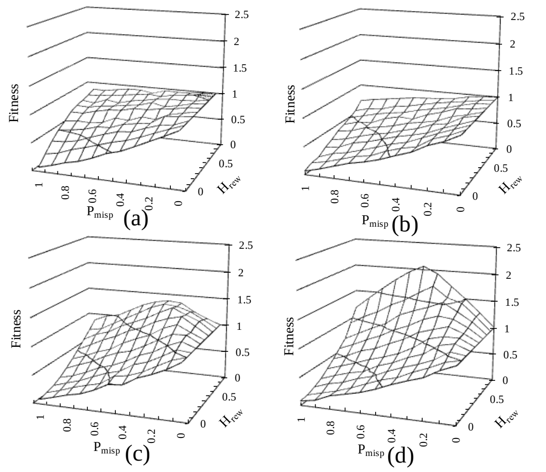

Fig. 3 (a) Fitness (a=0.3), (b) Fitness (a=1.0), (c) Fitness (a=3.0), (d) Fitness (a=10.0).

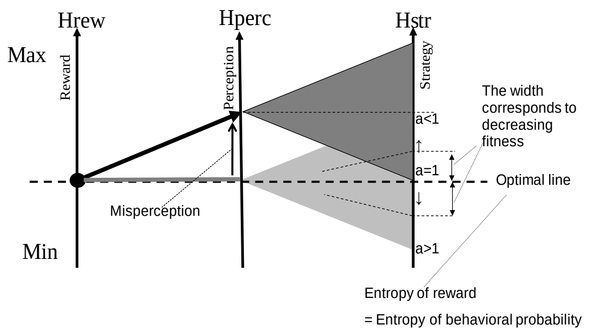

Fig. 4 Relations among misperception, strategy and fitness.

mechanism of the adaptivity of misperception. A strategy with a large a could generate the concentration of collective behavior, which decreased H_{str} below H_{rew}, while misperception has a tendency to increase H_{perc}. As a result, a gap between the distribution of the reward and the distribution of behavioral probability could be filled. Therefore, distribution of agents came closer to the optimal distribution (IFD).

VI. CONCLUSION

We constructed a simple mathematical model to investigate on the mechanism for misperception to be adaptive. When the agents adopt a behavioral strategy that tends to show overmatching, the entropy of behavior decreased. Hence, difference between the entropy of the rewards in environments and the entropy of behavior increased. Misperception increased the entropy of collective perception and thus decreased the difference. As a result, behavior of agents came closer to IFD as the optimal distribution. This result implies the possibility that misperception has a functional role to reduce a cognitive bias (e.g. majority bias) and can be adaptive from the evolutionary viewpoint.

REFERENCES

[1] Fretwell, S. D. and Lucas, H. L., "On territorial behavior and other factors influencing habitat distribution in birds", *Acta Biotheoretica*, Vol. 19, pp. 16-36 (1970).

[2] Arthur, W. B., "Inductive reasoning and bounded rationality", *American Economic Review*, Vol. 84, pp. 406-411 (1994).

[3] Arita, T. and Koyama, Y., "Evolution of linguistic diversity in a simple communication system", *Artificial Life*, Vol. 4, No. 1, pp. 109-124 (1998).

[4] Akaishi, J. and Arita, T., "Misperception, communication and diversity", *Artificial Life VIII*, pp. 350-357 (2002).

[5] Akaishi, J. and Arita, T., "Agent Based Modeling for Investigating Adaptivity of Misperception", *Systems and Computers in Japan*, Vol. 37, No. 12, pp. 96-1066 (2006).

[6] Akaishi, J. and Arita, T., "Agent Based Modeling for Investigating the Evolution of Misperception" (in Japanese), *IEICE Transaction of the Institute of Electronics, Information and Communication Engineers*, Vol. J88-D-I, No. 7, pp. 1161- 1164 (2005).

[7] Brumley, L., Kevin, B. K. and Kopp, C., An "Evolutionary Benefit from Misperception in Foraging Behaviour", *Progress in Artificial Life*, pp. 96-106 (2007).