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Agent-Based Modeling for Investigating Adaptivity of Misperception

Jin Akaishi[1] and Takaya Arita[2]

[1]Graduate School of Human Informatics, Nagoya University, Nagoya, 464-8601 Japan

[2]Graduate School of Information Science, Nagoya University, Nagoya, 464-8601 Japan

SUMMARY

Misperception is a term which is generally used in a negative sense. However, when information promoting a certain kind of behavior is obtained, it can happen that the diversity of the behavior is enhanced by the misperceptions of the individual in the population, resulting in a situation in which misperception works advantageously for the population. This paper presents this view in terms of four hypotheses, dealing with (1) the basic adaptivity of misperception, (2) basic properties of communication, (3) the adaptivity of misperception in communication, and (4) the behavioral specificity of information in the adaptivity of misperception. A simple agent model for the resource-searching problem is constructed. Direct misperception, which is misperception in the direct acquisition of information from the surrounding environment, and indirect misperception, which occurs when information is obtained through communication, are considered. Their effects are investigated by simulation experiments. It is shown that misperception enhances the diversity of agent behavior and can contribute to adaptivity. It is also shown that exact communication may decrease the diversity of agent behavior, and that adaptivity is decreased when false information is shared. A tendency for the adaptivity of misperception to decrease when the behavioral specificity in information terms is low is demonstrated. We believe that study of the adaptivity of misperception as a factor generating diversity will lead to new findings in cognitive science, memetics, and fundamental aspects of engineering. Syst Comp Jpn, 37(12): 96–106, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/scj.20266

Key words: misperception; diversity; adaptivity; agent-based model.

1. Introduction

Diversity is one of the core topics in various research fields. In particular, it has been discussed directly or indirectly in new research fields such as complex systems and artificial life [4]. An example is Arthur's "El Farol Bar" problem, which was derived by treating the inductive inference system as a complex adaptive system, focusing on self-organization and diversity [6]. It is considered a typical problem related to the origin of diversity. The problem is defined as follows.

Suppose that a collection of agents go to a bar every week. However, the number of seats in the bar is limited, and the agents can enjoy themselves there only if the number of agents coming to the bar does not exceed 60% of the whole population. The problem for each agent then is to decide whether to go or not to go to the bar. The only information available to each agent for making the decision is the past history of the number of agents who have gone to the bar.

Each agent has multiple predictors to estimate the number of agents who will go to the bar (such as prediction that the number will be the same as 2 weeks ago, or prediction based on the average for the past 4 weeks). In deciding whether or not to go the agent uses the predictor which is the most reliable (has the highest hit rate) on the basis of its past record, and makes a prediction as to whether the number of agents will exceed 60%. After ascertaining the number of agents who went to the bar in that week, the agent modifies the reliabilities of the predictors according to whether the use of each predictor resulted in a hit.

Such inference by the agents is based neither on deductive inference nor on an exact prediction model. If all agents make the prediction that the number of agents going to the bar will be smaller in the next week, all agents will go to the bar, and that predictor will not be used again. Consequently, the problem defined in "El Farol Bar" is that there is no general principle for prediction, and the diversity of the inference system will increase.

The following observations were made in Arthur's experiment. Even though the inference system is inductive and restricted, the diversity is adjusted through the dynamic balance of the "ecological system" of the set of predictors, and the number of agents going to the bar varies around 60%, which is the optimal level.

This kind of dynamics is generally produced by a frequency-dependent fitness function, in which the fitness of an individual with a certain behavior depends on the frequency of the behavior selected in the population. There have been studies of this aspect, especially in the fields of behavioral ecology and population genetics, which focus on equilibrium under particular conditions.

When selection is based on a frequency-dependent fitness function in which the fitness of an individual with a given character decreases as that character becomes more general in the population, it is called negative frequency-dependent selection. This implies that individuals with characters having lower frequency generally have greater fitness than individuals with more general characters. It has been shown by using game theory that such negative frequency-dependent selection enhances genetic diversity in the population [13].

When analyzing the origin and evolution of diversity, the role of communication or language seems important. Suppose, for example, that there is information promoting a particular behavior, and that the behavior has a negative frequency-dependence. If this information is shared in the population through communication, the frequency of occurrence of that behavior will increase, which will decrease the behavioral diversity in the population. This implies that the fitness of the population is decreased.

A simple example, separate from the viewpoint of the origin and evolution of diversity, is as follows. When information about a road which is not congested is made known to many persons by communication, they will exhibit the same behavior trying to use that road. This will result in a new inefficient situation.

Arita and Koyama designed a simple model of communication, considering instruction signals among animals, and are investigating the evolution of diversity [5]. Their model is as follows. The originator of a signal utters a word with certain semantics, and the receiver receives the word. The receiver consults its own vocabulary table for the semantics corresponding to the word and performs interpretation. If the interpretation is the same as the semantics of the originator's vocabulary table, the conversation is a success.

However, consider the case of a food call, which is an instruction signal reporting the presence of food. Even if the conversation is a success, there can be competition for food acquisition among the individuals that come in response to the food call. Thus, it is conceivable that some of the receivers will fail to obtain food even though they intended to do so. It is evident that negative frequency-dependence also exists in this communication system. In this case, the diversity of the vocabulary table is the focus of discussion.

Furthermore, there is a trade-off relation between the situation in which the agent takes all of the resources that it finds, and the situation in which it shares found resources with other agents. Simulation experiments on the evolution of vocabulary tables based on the amount of resource obtained have shown that the communication system autonomously adjusts the linguistic diversity according to the expansion of the population size, the decrease of the mutation rate, and the scarcity of resources.

Thus, from the viewpoint of the origin of behavioral diversity in a population, it is to be expected that various systems exist at various levels in which diversity of collective behaviors is produced autonomously, including humans, as is shown by the inference system investigated by Arthur and the communication system of Arita and colleagues. As one such system, we consider the recognition system, which forms the basis of the perception system.

The purpose of this study is to present and test the hypothesis that "misperception," consisting of incorrect recognition of information, should not be considered simply as an error with a negative effect, but should be considered as a function that generates diversity. A simple agent-based model is constructed for the resource-search problem [1–3], and a simulation is performed, focusing on the behavioral diversity of the population that arises as a result of misperception, as well as the change in fitness. This problem has a characteristic which can be called negative frequency-dependence, in the same way as the El Farol Bar problem, the minority game [8], and the blind hunger dilemma [12].

There have been few model studies from the viewpoint of computation theory that focus on the functional aspects of misperception in the recognition system. The multiagent model of Doran [10, 11] for the resource-search problem is one such study. In that study, an environment with a fatal zone in which an arriving agent dies is considered, and an experiment is performed, focusing on misperception regarding the presence and locations of other agents in the process of seeking a resource while avoiding other agents.

In this experiment, "misperception" implies incorrect belief in an event contrary to the truth, in which the agent is convinced of the presence of another agent who actually is not present. The experiment shows that the misperception in which the presence of an agent in the fatal zone is recognized can be adaptive. However, this study does not consider the adaptivity of misperception due to behavioral diversity in the population, but is based simply on the property that misperception results directly in adaptivity.

In this paper, the term "adaptation" is used in the same sense as in biology, especially in the theory of evolution and ecology, that is, a genetic character which is advantageous for survival or proliferation in a specified environment. Specifically, the terminology is as follows. "Fitness" represents the extent to which an ensemble of individuals with a certain character is superior to an ensemble of individuals without that character, in some sense (in this paper, the amount of resources obtained); "adaptive" implies that the character increases the fitness of the population; and "adaptivity" implies the adaptive property of the character.

2. Hypotheses

Misperception is defined as an action that generates a difference between the exact state of events in an environment and the state perceived as a result of information acquisition concerning the surrounding world through our sensory organs. Generally, misperception is considered to be nonadaptive. On the other hand, it is believed that when individuals gain information that promotes a particular kind of behavior, misperception has a favorable effect from the viewpoint of the population.

It is expected that the adaptivity of misperception will emerge in the following situation. First, the individuals in the population share information that promotes a particular behavior. This implies that the information diversity decreases from the viewpoint of the population. Thus, the behavioral diversity of the population decreases, making information sharing nonadaptive. Consequently, when misperception arises in the acquisition of information, the recognition by the population is diversified, and its behavior is also diversified.

In this situation, misperception can be adaptive by producing diversity. Furthermore, communication is a general means of sharing the information. Consequently, communication tends to promote a decrease in the diversity of recognition in the population. Thus, misperception in communication can also be adaptive.

Misperception is divided into two classes according to the information source. When misperception arises in the process of directly acquiring information from an information source that can be assumed to be correct (such as the environment in the narrow sense), it is called *direct misperception*. When misperception arises in the acquisition of information indirectly from an information source which is not verified as correct, it is called *indirect misperception*.

Figure 1 shows the flow of information and the generation of misperception. The rectangles in the figure represent individual agents and the arrows represent the flow of information. The hypotheses regarding the adaptivity of misperception are summarized as follows.

(1) When there exists a frequency-dependent behavior such that the adaptivity of the behavior decreases if the frequency of the behavior increases (the behavioral diversity decreases) in the population, misperception in the direct acquisition from the environment (direct misperception), of information which promotes that behavior and increases the frequency of the behavior can increase the fitness of the population.

(2) Information sharing of type (1) with other individuals by communication can decrease recognition diversity and decrease the adaptivity of misperception.

(3) Misperception of type (2) in communication (indirect misperception) can increase the fitness of the population in the same way as in item (1).

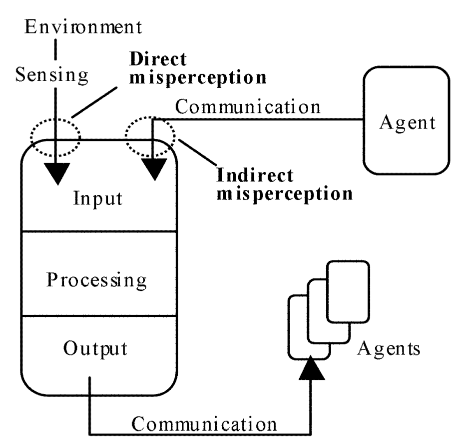

Fig. 1. Information flow and occurrence of misperception.

(4) The effects of items (1) to (3) depend on the degree to which the information specifies behavior by accelerating or deaccelerating it. For example, when information promotes all kinds of behavior except for one particular behavior (i.e., it suppresses only a particular behavior), the effect is minimized.

3. Model

3.1. Agent

In order to investigate the hypotheses described in Section 2, an agent-based model is constructed for the resource-search problem. The task is as follows. A two-dimensional planar field is sectioned into square cells, and agents (robots) search the field and try to obtain the resource (Fig. 2). At initialization of the field, the resource, or both the resource and poison, are uniformly distributed with a specified resource density. The locations of the resource and poison are kept invariant during the trial. When all of the resource or poison has been obtained by agents, it is restored, after one turn, at a rate of one unit of resource per turn at the same locations, up to the maximum resource level.

At initialization, the specified number of agents is distributed uniformly on the field. Each agent memorizes map information concerning the locations and amounts of the resource, obtained by its own perception or through communication. The map information consists of a memory area of the same size as the field. Each memory area stores a location represented by the x and y coordinates corresponding to the actual environment, the presence or

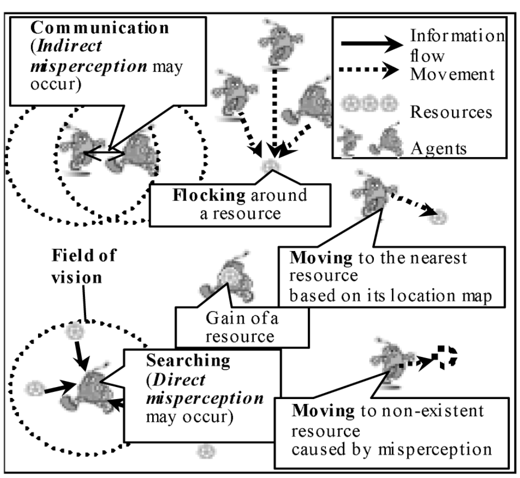

Fig. 2. Model for a resource-searching problem in a virtual multiagent world.

absence of the resource and the poison, the amount of the resource, and the amount of the poison, if it exists.

The agent recognizes the resource and the poison, and also other agents, within the field of view. The speed of an agent is the number of cells that the agent can travel through in a turn. The agent cannot move outside the field or into a cell containing another agent.

The agent uses its own sensors and recognizes the presence or absence of the resource and poison within the field of view, and also the locations and amounts of the resource and poison, if they exist. Its own map information is overwritten with the recognized information. Each agent can communicate one-to-one with the agents existing within its field of view. The performance of communication is expressed by a parameter. If the communication parameter is specified as "yes," the agent must communicate with another agent with which communication is possible. If it is "no," communication is not performed.

When communication is performed, the agents exchange information concerning all of the resource and poison that they have recognized. Information concerning the absence of the resource or poison is not transmitted. The agent that receives the information uses it to overwrite its own map information. If the exchanged information is not consistent, it is overwritten with new information. For example, if it is recognized that there is a resource at point A, and it is later recognized that there is no resource at point A, the absence of the resource at point A is overwritten onto the map information.

The agent moves on the basis of the map information obtained from its own recognition. It moves from its present position toward the position of the resource which is recognized to be the closest, in a direction that reduces the distance, regardless of the amount of the resource. If it is recognized that the resource is available at multiple locations equal distances away, the objective of movement is chosen at random. If no resource is recognized in the map information, the agent performs a random walk.

If there is information about the poison on the map, the agent does not move to that point. After movement, if some of the resource or the poison is in the same cell as the agent, the agent obtains all of the resource or poison in the cell. If the agent moves to a cell containing the poison by misperception, the amount of the poison is subtracted from the amount of the resource obtained.

3.2. Misperception

The kinds of information which are handled in the model are the locations of the resource and the poison, their presence or absence, and also their amounts. When the information is obtained by communication between agents or by the agent's own perception, a misperception can arise (Fig. 3).

It is assumed in this model that misperception can occur regarding the locations of the resource and the poison, and regarding their presence or absence. When a misperception occurs, the misperception concerning the locations of the resource and the poison or their presence or absence is selected exclusively. Selection is performed at random with the same probability.

The information concerning the presence or absence of the resource or the poison is called *attribute information*. The misperception of such information is called *attribute misperception*. The information concerning their locations is called *location information*, and misperception of such information is called *location misperception*.

When location misperception occurs, the attribute is correctly recognized but the location is recognized by assuming that the reported location is a point determined at random within the field. When an attribute misperception occurs, the location is correctly recognized but the opposite attribute is recognized: that is, it is recognized that the resource does not exist at a point at which it actually does exist.

In the acquisition of information on the poison, misperception occurs with a specified probability, producing location misperception or attribute misperception in which a point is misrecognized as an empty zone. Location misperception and attribute misperception can also occur for empty zones. In the case of attribute misperception, the point is recognized as containing the resource or poison.

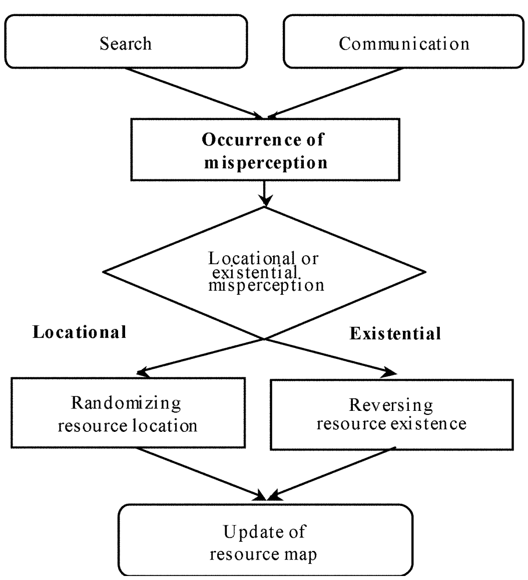

Fig. 3. Kinds of misperceptions.

3.3. Algorithm used

A simulation experiment is performed by the following procedure.

(1) Amounts of the resource and poison and also agents are distributed on the field with uniform probabilities.

(2) The agent performs communication with other agents in the cells in the field of view. When map information is exchanged, misperception occurs in accordance with the indirect misperception rate.

(3) The agent perceives the resource and poison information in a cell. In the process, misperception can occur in accordance with the direct misperception rate. The above procedures (2) and (3) are repeated for all cells in the field of view.

(4) The agent moves to the closest resource which is recognized. If there is no recognized target, the agent moves at random.

(5) The agent gains the resource or poison present in the same cell. The resources in the field are restored at the same points after the passage of time.

The above steps (2) to (5) are defined as a turn, which is repeated by all agents.

4. Simulation Experiment

4.1. Setting

In order to investigate the effects of misperception and communication on the behavior of the population, five different simulation experiments were performed, treating the effect of direct misperception (experiment 1), the effect of exact communication (experiment 2), the effect of indirect misperception (experiment 3), and behavioral specificity (experiments 4 and 5).

The parameters in the experiment were as follows. The number of turns was 5000. The field size was set as 10 × 10 (nontorus shape). The number of agents was 20. The field of view was defined as a radius of three cells with the agent as the center. The speed of movement was one cell per turn. The resource density was 20%. The maximum resource restoration rate was one per turn. The number of trials was 10.

In each experiment, the adaptivity of the population was evaluated in terms of the average amount of resource gained by all agents. The behavioral diversity and the recognition of all agents were evaluated by using a measure described later. Only the resource was distributed in experiments 1, 2, 3, and 5. The poison was distributed together with the resource in experiment 4.

4.2. Measure of diversity

We wish to investigate the hypothesis that adaptivity of misperception is achieved by adjustment of the diversity by misperception. Consequently, we investigate the relation between the behavioral diversity of the agents and misperception, and also the relation between adaptivity and misperception.

When an agent moves toward a resource, it moves by defining the objective of movement for each turn. Consequently, the following measure was used for the diversity in the behavior of the agents as an ensemble. The distribution of the targets of agent movement at a given time was considered as the signal distribution issued by the information source. Then, the calculated average amount of information, that is, the entropy, was used as the measure. A state in which many agents define a point on the field as a target of movement is a state with low diversity, and a state in which the targets of movement are scattered and have less duplication is a state with high diversity.

The behavioral diversity H_b is defined as follows:

$$H_b = \sum_{i=1}^{m} -\frac{a_i}{n} \log_2 \frac{a_i}{n}$$

Here m is the number of cells defined as the targets by agents, n is the total number of agents, and a_i is the number of agents that define the i-th point as a target of movement; the maximum of m is n and the minimum is 1.

On the other hand, the recognition diversity represents the degree to which the recognition of the agents is diversified. The criterion of recognition diversity is defined as follows. The rate of recognition of the attribute of a cell among the agents is treated as the rate of issuance of the signal by the information source, and the entropy is calculated. The sum of the entropy for all cells is defined as the measure of recognition diversity and is called the information diversity. A state in which all agents have the same recognition for all cells is a state with low diversity, and the state in which the possible cell attributes are recognized at a uniform rate is the state with the highest diversity.

The information diversity H_p is defined as follows:

$$H_p = \sum_{j=1}^{c} \sum_{i=1}^{k} -\frac{p_{ji}}{n} \log_2 \frac{p_{ji}}{n}$$

Here c is the total number of cells, k is the number of states in which a cell can be recognized, p_{ji} is the number of agents that recognize the state of cell j as i, and n is the total number of agents. The value of k is usually 2, representing the two states of empty zone or resource, but is 3 when the poison state is added in the experiment on behavioral specificity.

4.3. Effect of direct misperception

We first investigate the basic properties of misperception. The effect is investigated for the case in which information acquisition by communication is not included, and misperception can occur only in the agent's own perception. In other words, only direct misperception is considered. The direct misperception rate is varied from 0% (no direct misperception) to 100% (misperception always occurs), and the effect of direct misperception is investigated.

Figures 4 and 5 show the experimental results. Figure 4 is an enlargement of the peak of the amount of the resource obtained when the direct misperception rate is varied. Figure 5 shows all changes of the average amount of resource obtained, the behavioral diversity, and the information diversity, as functions of the direct misperception rate.

We see from Fig. 4 that there is a peak in the amount of resource obtained near a direct misperception rate of 3%. Compared to the case of a direct misperception rate of 0%, where no misperception occurs, the average of the amount of resource obtained increases by approximately 40% at the peak. We see from Fig. 5 that both the behavioral diversity and the information diversity increase rapidly with the amount of resource obtained, up to a direct misperception rate of 3%, and then increase slowly.

Figure 6 shows the change in the amount of resource obtained as a time series. The moving average for two intervals is shown. When the misperception rate is 0%, the amount of resource obtained increases slowly in the first five turns, then remains almost constant. This seems to indicate a situation in which the agents approach the resource first, and then securely gain all of the resource in the neighborhood.

When the misperception rate is 3%, the amount of resource obtained increases up to 500 turns, and then settles into a steady state. The reason seems to be as follows. The misperception diversifies the collective behavior, enlarging

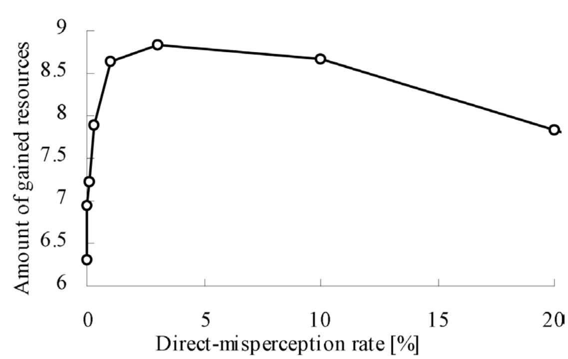

Fig. 4. Effects of direct misperception.

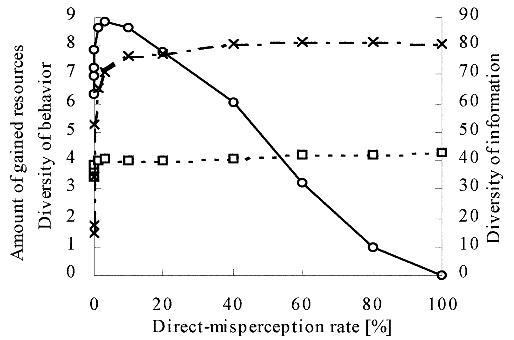

Fig. 5. Effects of direct misperception (continuous line: the amount of the average gained resource; dotted line: diversity of behavior; dash-dotted line: diversity of information).

the range of search by the population. This has an effect that overrides the negative effect of making resource acquisition difficult by the misperception.

It is also seen that the oscillation of the amount of resource obtained is increased when the misperception rate is increased. The amount of resource obtained remains almost constant when the misperception rate is 0%. A slight oscillation is observed at 3%, and the amplitude of the oscillation is comparable to the size of the resource when the rate is 60%. The reason seems to be that the certainty of obtaining the resource is degraded with an increasing misperception rate.

These results show that direct misperception produces errors in individual recognition which can be adaptive by diversifying behavior. The behavioral diversity due to direct misperception has a positive effect of enlarging the search range of the individual agents and preventing the convergence of agents on a particular resource, and also a negative effect of making it difficult to obtain the resource securely. It is inferred that these effects are balanced near a direct misperception rate of 3%, making the system adaptive.

4.4. Effect of communication

In this experiment, communication between agents is introduced. The agent obtains information by its own sensors or through communication with other agents. In order to investigate the effect of communication itself, it is assumed in this experiment that indirect misperception does not occur. As in the case examining the effect of direct misperception, the direct misperception rate is varied and the characteristics of communication are observed.

Figures 7 and 8 show the experimental results. Figure 7 is an enlargement of the part of the result in which the amount of resource obtained and the behavioral diversity are compared for the case including communication and the case in which only direct misperception occurs. Figure 8 shows a comparison of the amount of resource obtained, the behavioral diversity, and the information diversity as a whole.

When communication is introduced, the amount of resource obtained increases compared to the case without communication, as can be seen for direct misperception rates from 0.01% to 0.3% in Fig. 7. As is evident from Figs. 7 and 8, however, the behavioral diversity, the information diversity, and the amount of resource obtained all decrease at a direct misperception rate of 0% when communication is introduced. The reason seems to be as follows. The information diversity decreases when exact information is shared by the population. Then, agents converge excessively on a particular resource, decreasing the behavioral

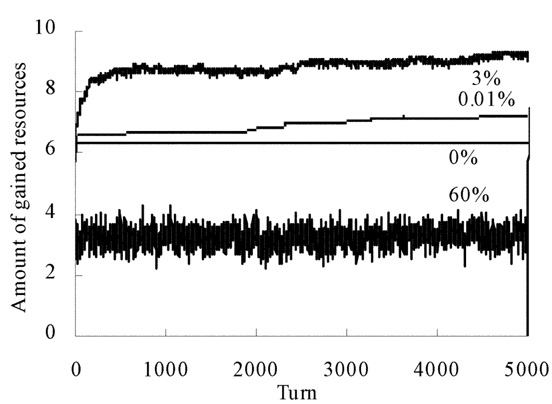

Fig. 6. Effects of direct misperception: change in the amount of gained resource.

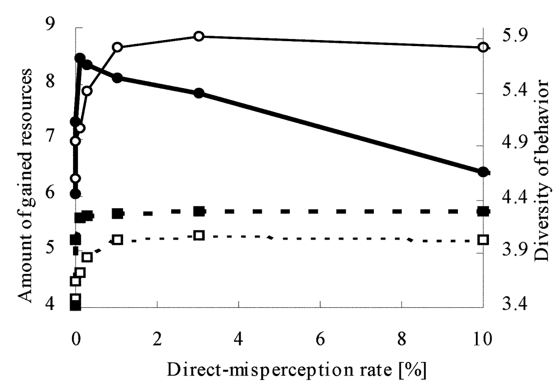

Fig. 7. Effects of communication (thick line: with communication; thin line: without communication; continuous line: the amount of the average gained resource; dotted line: diversity of behavior).

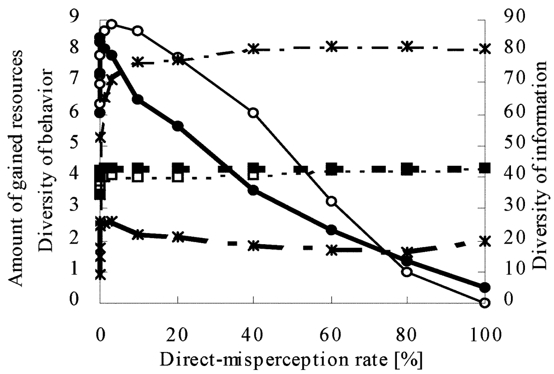

Fig. 8. Effects of communication (thick line: with communication; thin line: without communication; continuous line: the amount of the average gained resource; dotted line: diversity of behavior; dash-dotted line: diversity of information).

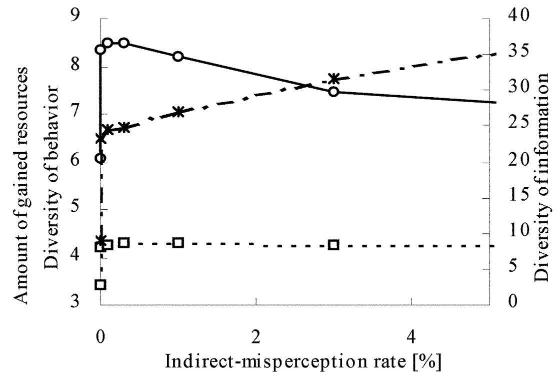

Fig. 9. Effects of indirect misperception (continuous line: the amount of the average gained resource; dotted line: diversity of behavior; dash-dotted line: diversity of information).

diversity, which then decreases the amount of resource obtained.

It is also shown that the amount of resource obtained is decreased by approximately 40% as a result of introducing communication when the direct misperception rate exceeds 1%. The reason seems to be as follows. The false information resulting from direct misperception is excessively shared by the population. This makes secure acquisition of the resource difficult and decreases the amount of resource obtained. The time course of the amount of resource obtained is similar to that in the experimental results for direct misperception.

These results show that communication decreases the behavioral diversity and decreases the adaptivity of misperception when the shared information is exact. In addition, they show that the adaptivity of misperception can decrease when a large error is included in the shared information.

4.5. Effect of indirect misperception

The effect of indirect misperception is investigated by fixing the direct misperception rate at 0% and varying the indirect misperception rate from 0% (what is sent by the sender is always correctly received) to 100% (what is sent by the sender is never correctly received). Figure 9 shows the experimental results. We see from the figure that the adaptivity and the behavioral diversity both reach their maxima when the indirect misperception rate is 0.1%, increasing the average amount of resource obtained by approximately 40% compared to the case of an indirect misperception rate of 0%.

It is also shown that the information diversity increases with the indirect misperception rate. This seems to indicate that the information shared by communication is decreased by indirect misperception. The time course of the amount of resource obtained is similar to that in the experimental results for direct misperception.

These results show that the appropriate indirect misperception prevents a decrease in the diversity of collective recognition by communication, with the result that communication can become adaptive.

4.6. Behavioral specificity

In the experiments up to this stage, information promotes the movement of agents toward the locations of the resource. From this viewpoint, an experiment was performed to investigate the degree of behavioral specificity as enhanced by information, that is, the adaptivity of misperception, when behavioral specificity changes. The poison is introduced in this investigation in order to investigate the effect of the information with apparently the lowest specificity, which promotes all behaviors except for a particular behavior, that is, information that suppresses only a particular behavior.

In this experiment, it is assumed that misperception concerning the resource does not occur. When attribute misperception regarding a poison location or a blank zone occurs, they are perceived respectively as a blank zone or a poison location and never perceived as the resource. The density parameter for the poison is set as 20%, the same as for the resource. The maximum rate of restoration of the poison in a turn is set as 1, which is also the same as for the resource.

First the direct misperception rate is varied from 0% to 100%, and the effect of direct misperception for the poison is determined for comparison with the effect of direct misperception. If the amount of resource obtained is simply compared, it is difficult to compare the effect of misperception, since it is obvious that the amount of resource obtained decreases when the poison is introduced. In order to see more clearly the change in the amount of resource obtained versus the misperception rate, the relative amount of resource obtained is compared by normalizing it to that at a direct misperception rate of 0%. The agent uses only its own sensors in the search for the resource, and communication with other agents is not included. Thus only direct misperception can occur.

Figure 10 compares the relative amount of resource obtained in the cases where poison is introduced and is not introduced. The increase in the behavioral diversity is approximately 10% less for the misperception of the poison than for the misperception of the resource. The amount of resource obtained remains almost the same in the presence of misperception of the poison, being increased by approximately 25% at the maximum. Misperception of the resource increases the amount of resource obtained by approximately 40% at the maximum for a direct misperception rate of approximately 3%. It is inferred from this result that whether direct misperception increases the behavioral diversity depends on the behavioral specificity.

Next, an experiment on indirect misperception was performed. Figure 11 shows the relative amount of resource obtained in the case of an indirect misperception rate of 0%, and also the behavioral diversity for the cases in which the poison is introduced and not introduced. Indirect misperception of the resource increases the relative amount of resource obtained by approximately 40% at the maximum, but the adaptive effect of indirect misperception of the poison results in an increase of only about 20%.

The behavioral diversity also increases by approximately 20% when misperception of the resource is introduced, but the increase is only about 2% when misperception of the poison is introduced. Thus, it is inferred in the case of indirect misperception too that whether the behavioral diversity is increased depends on the behavioral specificity.

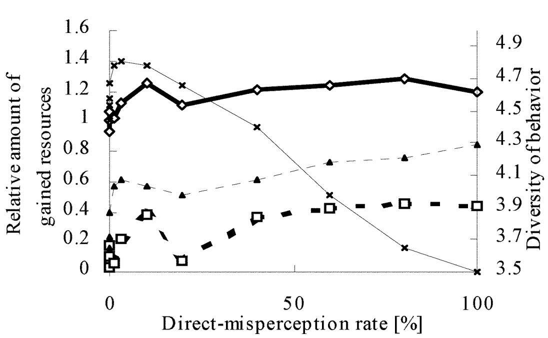

Fig. 10. Effects of direct misperception for behavioral specificity (continuous line: relative gained resource; dotted line: diversity of behavior; thick line: with poisons; thin line: without poisons).

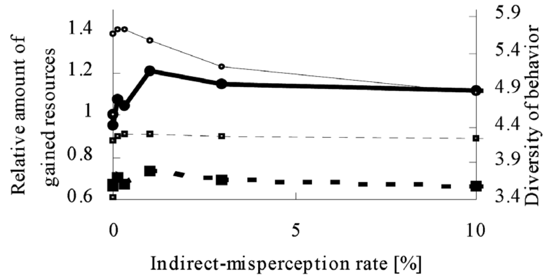

Fig. 11. Effects of indirect misperception for behavioral specificity (continuous line: relative gained resource; dotted line: diversity of behavior; thick line: with poisons; thin line: without poisons).

The difference between the resource and the poison shown in the above experiments is the difference in behavioral specificity promoted by the information concerning them. The possession of information concerning the resource promotes a particular behavior, and the possession of information concerning the poison promotes a wider range of behavior on a relative basis, excluding a particular behavior. Information promoting a wide range of behavior has a smaller effect even if the diversity is further increased. Consequently, the effect of misperception of the poison is smaller than that of misperception of the resource.

In order to investigate the relation between the effect of misperception and behavioral specificity from another viewpoint, an additional experiment was performed without introducing the poison. The settings of the resource distribution and other factors were the same, but it was assumed that the agent recognized that the resource existed not only at the exact point, but also in a range of a 3×3 square centered on that point.

In other words, in the model up to this stage (called the basic model), the resource is considered as an information source with high behavioral specificity that can be clearly recognized on the ground. But the model in the experiment (called the extended model) assumes the resource to be an information source with low behavioral specificity, whose location can be determined roughly but is difficult to identify clearly, as in the case of underground resources.

The parameters used in the experiment are as follows for both the basic and the extended models. The field size is 20×20. The number of individual agents is 20. The resource density is 5%. The other parameters are the same as in the experiments up to this stage. The information specificity differs between the basic and the extended models, which will obviously affect the actual amount of resource obtained and the behavioral diversity to differ. Thus, it is difficult to see the effect of misperception due to the difference in behavior specificity by comparing only such results as the actual amount of resource obtained. Consequently, in both the basic and the extended models, the result is normalized before comparison, using the result for the case without misperception (misperception rate of 0%) as the reference.

Figure 12 shows the experimental results. The horizontal axis is the direct misperception rate. The vertical axis represents both the relative amount of resource obtained and the relative behavioral specificity, with the case of a misperception rate of 0% as the reference. Comparing the relative amount of the resource obtained in the figure, it is evident that the basic model with low behavioral specificity is more adaptive than the extended model for direct misperception rates below 20%. For the relative behavioral diversity too, the change is larger in the basic model. Thus, it is shown that the extended model is less affected by change of the misperception rate than the basic model.

The reason seems to be as follows. In the extended model, the location of the resource is represented by a wider range than in the basic model. This increases the amount of information concerning the resources which the agent obtains from the information source. Consequently, the number of movement objectives that the agent can select is increased. This increases the behavioral diversity even in the absence of misperception, which consequently reduces the effect of misperception.

The same experiment was also performed for indirect misperception with the same settings, and similar results were obtained. These results support our hypothesis that the effect of misperception is enhanced when the behavioral specificity is high.

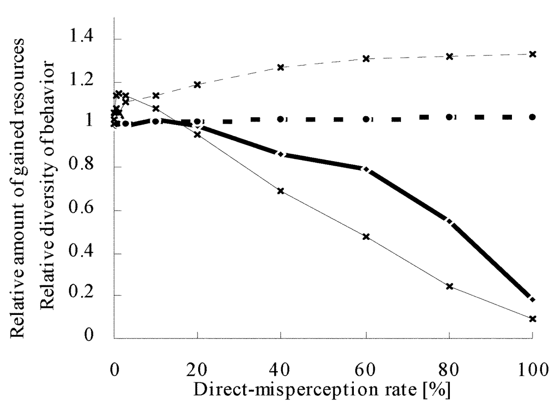

Fig. 12. Effects of direct misperception for behavioral specificity: expanded model (thin line: base model; thick line: expanded model; continuous line: relative gained resource; dotted line: relative diversity of behavior).

5. Conclusions

This paper is based on the view that the diversity inherent to humans and other species can be generated autonomously by factors such as negative frequency-dependent characteristics. We present the hypothesis that misperception capable of generating diversity in the perception system can adjust the diversity of the collective behavior and make it adaptive. The hypothesis is investigated quantitatively by simulation experiments.

It is shown experimentally that misperception enhances the diversity of recognition and behavior by the agents, making it more adaptive (hypotheses 1 and 3). On the other hand, it is verified that exact communication decreases the behavioral diversity of the agents, which can decrease the adaptivity of misperception (hypothesis 2). It is also verified that the system can be nonadaptive when the information shared by communication contains many errors. Cases in which the kinds of behavior promoted by information have different specificity are compared. All of the results seem to support the hypothesis of behavioral specificity (hypothesis 4) concerning the adaptivity of misperception. It is left for future study to show more clearly the relation between behavioral specificity and the effect of misperception.

We expect that the study of the adaptivity of misperception, as a factor generating diversity, will lead to new findings in various interesting topics. The first is explanation of the incompleteness of the human sensory organs from the functional viewpoint. It is known that sensory organs often make errors. It may be possible to account for these errors from the viewpoint of evolution, in addition to structural and physical limits. As an extension, we plan to investigate this topic as follows, using the model presented in this paper. The misperception rate is defined as a genetic parameter of each agent. By performing selection using the amount of resource obtained as the fitness of the agent, evolution of the misperception rate will be achieved.

The second point is to characterize this adaptivity of misperception in the discussion of memetics, where the cultural aspect of humans is interpreted by an analogy with genetics [7]. Dawkins considers the meme as a replicator in the same way as the gene, and defines three factors—longevity, fecundity, and exactness of replication—as the elements of success for a replicator [9]. However, the results of the experiments described in this paper indicate that error in information replication is adaptive, which contradicts the third element. There has been much discussion of contradictions between the gene and the meme, but it is interesting that the existence of such contradictions is clearly shown at a level which is not concerned with information content.

The third point is the possibility of a counterargument against the progress of engineering technology. For example, the issue with regard to group robot systems is that endless improvement of the sensor sensitivity of robots will not necessarily improve the performance of the whole system, or that there can be situations in which noise may play a functional role. We are now developing a group robot system in order to investigate this point.

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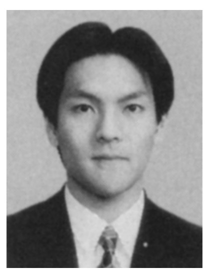
AUTHORS (from left to right)



Jin Akaishi received his B.E. and M.E. degrees in communications engineering from Tohoku Institute of Technology in 1996 and 1998 and joined Fujitsu Business Systems. He is currently a doctoral student in the Graduate School of Human Informatics at Nagoya University.

Takaya Arita received his B.S. and Ph.D. degrees from the University of Tokyo in 1983 and 1988. He is now a professor in the Graduate School of Information Science at Nagoya University. His research interest is in artificial life, in particular the following areas: evolution of language, evolution of cooperation, swarm intelligence, and interaction between evolution and learning.