Misperception, Communication and Diversity

Jin Akaishi[1] and Takaya Arita[2]
Graduate School of Human Informatics
Nagoya University
Chikusa-ku, Nagoya, Aichi, 464-8601 Japan
[1]jin@create.human.nagoya-u.ac.jp, [2]ari@info.human.nagoya-u.ac.jp

Abstract

It is commonly agreed upon that misperception is detrimental. However, misperception might have a beneficial effect from a collective viewpoint when individuals mispercept incoming information that promotes a specific kind of behavior, which leads to an increase in diversity. First, this paper proposes our hypothesis regarding adaptive property of misperception based on the argument of the relationship between misperception and behavioral diversity, and the effects of communication on diversity. Then, a simple computational model is constructed for a resource-searching problem by using the multi-agent modeling method. We investigate both direct misperception, that are caused when obtaining information directly from surrounding environment, and indirect misperception, that are caused when obtaining information indirectly through communication by conducting simulation experiments. The experimental results have shown 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. This paper also discusses a correlative relationship between direct misperception and indirect misperception. We believe that the study on adaptive property of misperception based on an innovative frame of reference and a powerful methodology in the field of complex system or artificial life would shed light on fundamental issues in cognitive science, memetics and engineering.

Introduction

Diversity has been one of the central themes in various research fields. Especially, studies in complex systems or artificial life have directly or indirectly focused on diversity because these new study fields can provide an innovative frame of reference and a powerful methodology (Arita 2002). The "El Farol" bar problem is a typical economic problem devised by Arthur (1994), which focuses on diversity and self-organization of an inductive-reasoning system as a complex adaptive system. In his game, 100 agents decide at each step whether or not to go to the bar. However, space is limited and the evening is enjoyable (each agent receives a positive utility from attending the bar) if fewer than 60% of the possible 100 are present. Only information available is the numbers who came in past weeks. Each agent possesses and keeps track of an individualized set of predictors (e.g. the same as 2 weeks ago or an average of the last 4 weeks). In his experiment, agents modified the extent to which they rely on predictors, according to their accuracy in previous weeks. There is no deductively rational solution or no correct expectational model. Any commonalty of expectations gets broken up, because if all believe few will go, all will go, which would invalidate that belief. Therefore, diversity in the reasoning system will be forced to increase. The results of the experiment have shown that attendance at the bar fluctuates unpredictably around the optimal level of 60 based on an "ecology" of active predictors.

This problem can be seen as an instance of situations in which the fitness of an individual's behavior may depend upon how many others are also doing it. In general, this kind of dynamics can be generated by frequency-dependent fitness functions and has been studied especially in behavioral ecology and population genetics focusing on the equilibrium states or specific states under limited conditions. In negative frequency dependent selection, the fitness of a trait decreases as it becomes more common, in other words, less frequent traits have higher fitness than common ones. Game theory has proved that negative frequency-dependent selection favors increase in genetic diversity in populations (Maynard Smith 1982).

When we start from the El Farol bar problem and aim to explore the origin and evolution of diversity in various complex systems based on the frame of reference and a powerful methodology of the fields of complex systems or artificial life, it is very important to investigate the role of communication or languages. Suppose that there is information that promotes a rate of occurrence of a specific behavior, and that this behavior has a negative frequency-dependent property. Then, information sharing by communication would promote a rate of occurrence of a specific individual behavior and would reduce diversity in collective behavior, which could decrease collective fitness as a result.

There have been some studies that explicitly explore the origins and nature of linguistic diversity using micro-simulation models (Livingstone 2002). Arita and Koyama (1998) constructed a simple computational model for a communication system that is designed with regard to referential signaling in nonhuman animals. In their model, a conversation is realized when there are a signaler that utters a word and a listener that has the word in its vocabulary table where its meaning is equal to the meaning in the signaler's vocabulary table. However, for example, in the case of food call, some of the listeners that wish to obtain the food might nonetheless fail to do so, because of feeding competition. Therefore, a kind of negative frequency-dependent property exists in the communication system itself, and the diversity in the vocabulary table would become a subject of discussion. There is a tradeoff between the monopoly of the resources discovered by an agent itself and the sharing of the resources discovered by other agents (to be exact, sharing with risks of additional competition). The evolutionary dynamics of vocabulary sharing was analyzed based on computational experiments. The results imply that the communication system adapts to the growth of population size, mutation rate, or restriction on resources by increasing its linguistic diversity.

Origin and evolution of diversity in complex systems can be approached from different layers including reasoning systems conducted by Arthur and communication systems conducted by Arita and Koyama. We revisit the issue of the perception system as the fundamental part of the cognition system, and propose a significant aspect of it as an origin of diversity in information and behavior by constructing and running a simple computational model of misperception. We believe that this series of study on adaptive property of misperception would shed light on following challenging themes:

1. Human cognitive function — Can we comprehend imperfect human cognition or defective human discriminative organs based on evolutionary explanation?,

2. Memetics — Can we figure out the optimal mutation of the memes based on diversity in collective behavior driven by the memes in population?,

3. Engineering — May further improvements in sensors of robots lead to decrease in system performance caused by decrease in behavioral diversity of robots?

Very few computational studies have been conducted on adaptive property of misperception so far. Doran (1994, 1998) constructed a computational model in which the agents might have collective misbelief for studying ideologies in human societies. "Misbelief" is intended to mean a belief in a proposition that does not correspond to the actual state of affairs of the world (e.g. the belief in non-existing agents). He showed that collective misbelief could be beneficial to a population of agents by conducting a simulation, where adaptive property was not generated by diversity in behavior or information, and misperception never happened during communication.

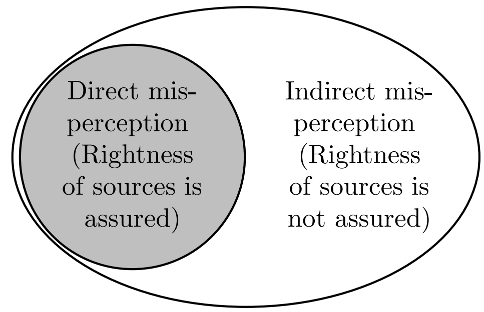


Figure 1: Classification of misperception

Hypothesis

Misperception is defined as a process that produces a deviation between the actual state of affairs of the world and the perceived state when obtaining information about our surrounding world specifically through our senses. It is natural to suppose that collective misperception must be detrimental. However, misperception might have a beneficial effect from a collective viewpoint when individuals misidentify or mispercept incoming information which promotes a specific kind of behavior. Suppose that there is traffic information that traffic on a certain road is very light during rush hours and car drivers get the information in a moment. It is easy to imagine that cars would rush to the road and be forced to slow down after all. In this case, if a proportion of drivers would misperceive the information then the traffic jam might ease off.

Adaptive property of misperception is supposed to show itself typically as follows. First, individuals in a population share information that has a nature that promotes a specific behavior. This means that informational diversity decreases from a collective viewpoint. Then behavior of the population is homogenized and information sharing would be unadaptive as a result. On the other hand, if misperception occurs when obtaining information, the collective belief will be diversified and then collective behavior will be also diversified. In this context, misperception can be adaptive owing to diversification after all. Communication is a method of sharing information in general. In other words, communication tends to reduce the informational diversity and homogenize collective perception. Therefore, there is a possibility that misperception in communication is also considered to become adaptive.

Misperception can be classified into two categories depending on information sources (Figure 1). Misperception which occurs when each individual obtains firsthand information from passive and certified sources (e.g. en-

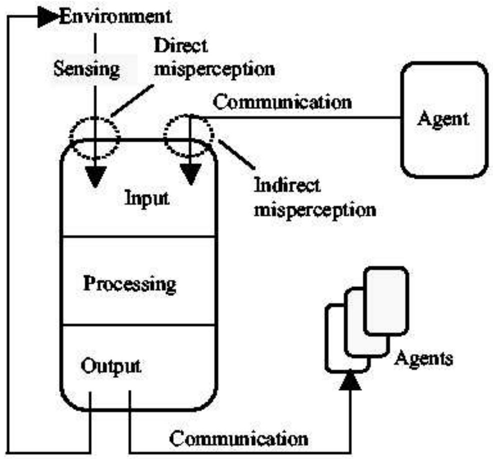


Figure 2: Information flow and occurance of misconception

vironment) is termed *direct misperception*. On the other hand, misperception which occurs when each individual obtains indirect information from active and not-certified sources (e.g. other agents) is termed *indirect misperception*. Figure 2 shows the flow of information and occurrence of misperception. The rectangles express agents and the arrows indicate information flow.

Here, we summarize the hypothesis regarding adaptive property of misperception as follows.

1. Direct misperception of information promoting a rate of occurrence of a specific behavior increases diversity in behavior of a population, which can result in increase in collective fitness.

2. Information sharing by communication promotes a rate of occurrence of a specific individual behavior and reduces diversity in collective behavior, which could decrease collective fitness as a result.

3. Indirect misperception during communication could increase the collective fitness as is the case with 1).

4. The effects of adaptive property of misperception depend partly on specificity of the behavior accelerated by the information. If the information promotes all behaviors but one specific behavior (which means that the information prohibits a specific behavior), the effect will be minimized.

Model

Agents

Our hypothesis is tested adopting a foraging task on a two-dimensional field where autonomous mobile robots (agents) wander in search of food resources (Figure 3)

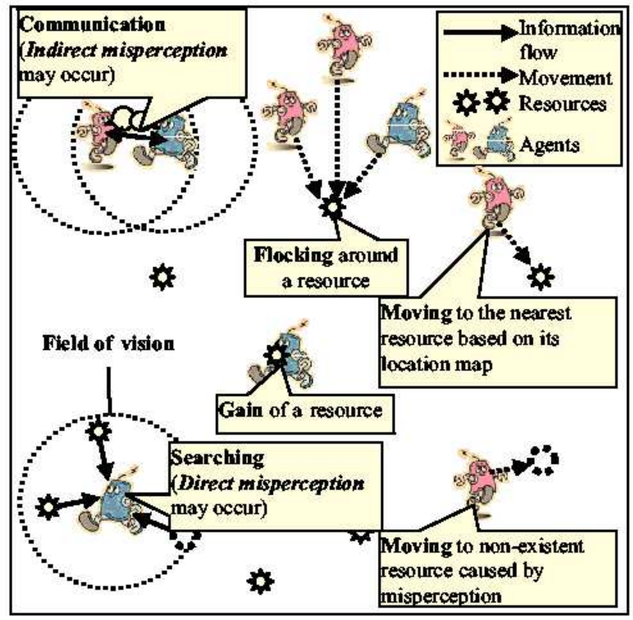


Figure 3: Model for a resource-searching problem in a virtual multi-agent world

(Akaishi & Arita 2002). Resources are distributed uniformly when initializing the field. They have fixed locations during a run. When an agent gains a resource, the amount of the resource becomes zero. Then, after a turn has passed, the amount of the resource is increased at a rate of one unit per turn at the same place until the maximum value.

Agents are distributed randomly in the field at the start of each trial run. Each agent has a resource map with information about location and amount of resources. This information is obtained either by using their own visual sensors or by communicating with other agents. Each resource map is expressed by a memory area corresponding to the whole of the field, where each cell stores the information about whether resource exists or not, and the amount of the resource if it exists.

Each agent perceives both resources and the other agents in its field of sight that is represented as a square centering on the agent. The field of sight and the range of movement per turn are shown in Figure 4. "A" in this figure expresses an agent, light gray cells express the field of sight, and light gray cells and dark gray cells express the range of movement. Agents cannot move into a cell occupied by another agent. Movement speed of each agent per turn is expressed by the number of grids. Agents perceive existence/nonexistence of resources in their field of sight, and in case of existence, they obtain information of the location and the amount of them by using their own visual sensors. Recognized information is overwritten in their resource maps.

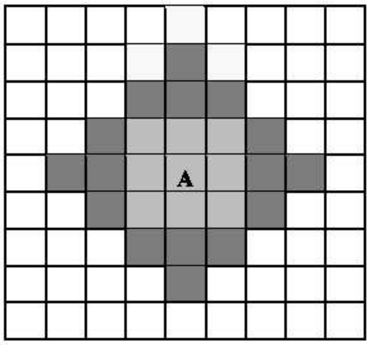


Figure 4: Field of sight (light gray cells) and movement range (light gray and dark gray cells).

We have conducted simulation experiments under following two conditions:

1. Agents always have one-to-one communication with other agents if possible,
2. Agents never have communication with other agents.

They communicate the information of the location and the amount of the resources among them in the former case. The information of nonexistence is not communicated. Communicated information is overwritten in their resource maps even if new information conflicts with old information. For example, an agent recognizes a resource at location A by using communication. Later, if the agent itself recognizes nonexistence of the resource at location A, this new information is overwritten in its resource map. In the case that information that comes from visual sensors and information that comes from the other agents through communication are contradictory to each other, the former is given priority over the latter.

Each agent moves toward the nearest resource based only on the information of its own resource map, which does not depend on the amount of resources. A target resource is selected randomly if more than one resource are at equal distances. Agents will perform a random walk when their resource maps have no information of resource existence. When agents move to the cell where a resource exists, they get all of the resource.

Occurrence of misperception

There is a possibility that misperception occurs when agents get information by their own visual sensors or through communication (Figure 5). Three kinds of information concerning the resources (location, existence/nonexistence, and amount) are communicated. We have conducted simulation experiments on the condition that misperception can change the information of location or existence/nonexistence. When misperception

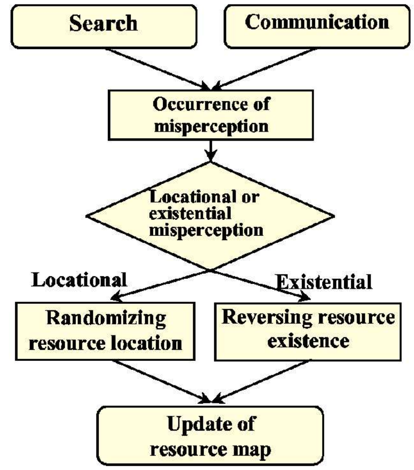


Figure 5: Information flow and occurrance of misperception.

occurs, one of the following two types of information is selected randomly with equal probability as follows. In the case that misperception of location happens, random location concerning the communicated resource is stored in the resource map of the agent while the other information is communicated precisely. In the case that misperception of existence happens, existence-nonexistence is reversed concerning the communicated resource.

Algorithm

Simulation experiments are conducted as follows (Figure 6).

1. Resources and agents are distributed uniformly over the field.
2. Agents communicate with other agents within their sight.
3. Misperception might occur with a given probability ("indirect-misperception rate").
4. Agents might perceive resources. If so, misperception might occur with a given probability ("direct-misperception rate").
5. Each agent moves toward the nearest resource based on information of its own resource map. Agents with no resource in their resource maps move in a random direction at the specified speed.
6. Agents get the resources existing in their own cells. Resources will recover gradually in the same location.

The above cycle from 2) to 6) is termed "a turn" and will be conducted again and again.

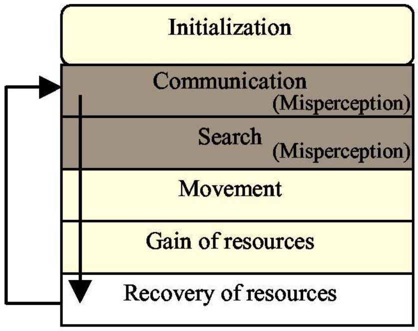


Figure 6: Flow of the process.

Simulation experiments

Experimental setting

We conducted following five simulation experiments so as to examine the effects of misperception on the behavior of the population in relation to the effect of communication.

Experiment 1: Effects of direct misperception.

Experiment 2: Effects of communication.

Experiment 3: Effects of indirect misperception.

Experiment 4: Effects of indirect and direct misperception.

Experiment 5: Effects of behavioral specificity.

Experiments were conducted using following parameters:

Number of turns in a trial run:	10000
Field size:	50 × 50 (non torus)
Number of agents:	150
Sight:	3 × 3
Speed:	3 / turn
Resource density:	5 %
Maximum amount of each resource:	1
Number of trial run (Experiment 1, 2, 5):	6
Number of trial run (Experiment 3, 4):	60

The amount of the average obtained resource by all agents is evaluated as a fitness value of the population in all of the experiments in this paper, and some graphs have more sampling points than other graphs in order to search for peaks.

Effects of direct misperception

Agents searched for resources by using their own visual sensors, and didn't communicate with other agents. Thus, only direct misperception could happen in this experiment. We changed direct-misperception rate from

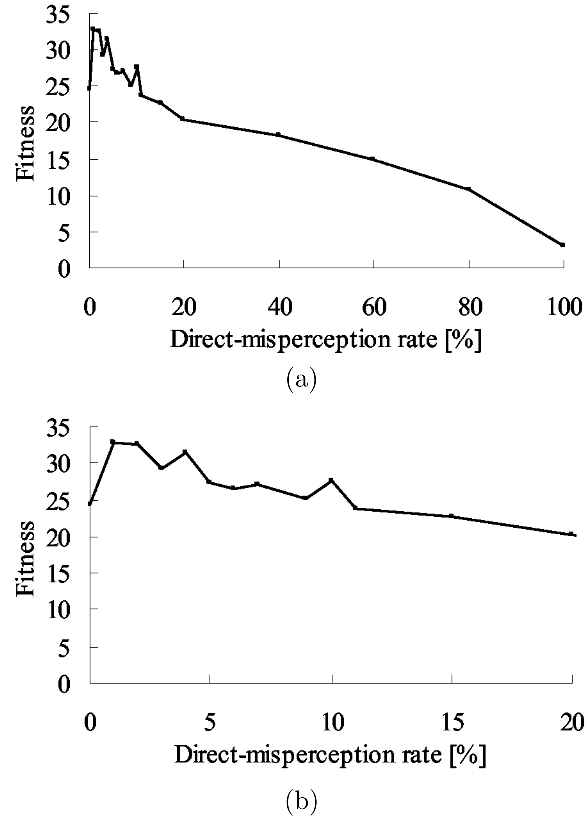


Figure 7: Flow of the process.

0% (without misperception) to 100% (with misperception at all times), and investigated effects of direct misperception.

The results of the experiment are shown in Figure 7 and 8. Figure 7 shows the effect of direct misperception on fitness when varying direct-misperception rate. It is shown that the fitness has a peak when direct-misperception rate is around 1%. The fitness in the case that direct misperception is 1% is about 35% greater than the fitness in the case that no direct misperception happened (0%). The reason is supposed to be that the search range was enlarged because direct misperception diversified individual behavior. In this context, it is considered that misperception could contribute to adaptivity.

Figure 8 shows time transition of fitness by moving average, where each line corresponds to each value of direct-misperception rate. Before 2000 turns, fitness in the case that direct-misperception rate is 10% is larger than the one in the case with 1%. After that, fitness was stable at the value around 28. The cause of this result is that behavioral diversity made by direct misperception (10%) was larger than diversity in the case with 1%, which caused the search area to be wider. On the other hand, however, the fitness in the case with 10be-

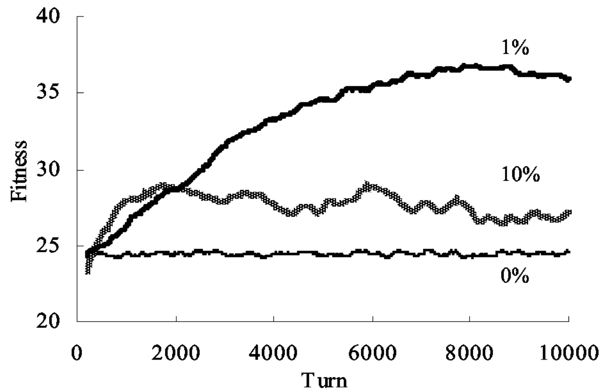


Figure 8: Flow of the process.

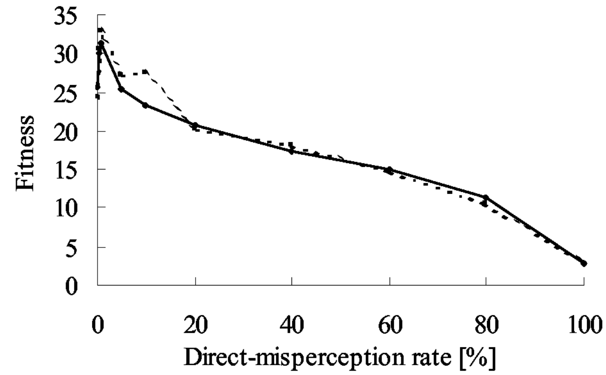
cause agents could not surely gain resources because the misperception rate was too high. The reason of slight decrease after 8000 turns in the case with 1% is supposed to be that almost all locations of resources had been found by 8000 turns and thereafter the negative effect of misperception began to dominate the system to a certain extent.

Effects of communication

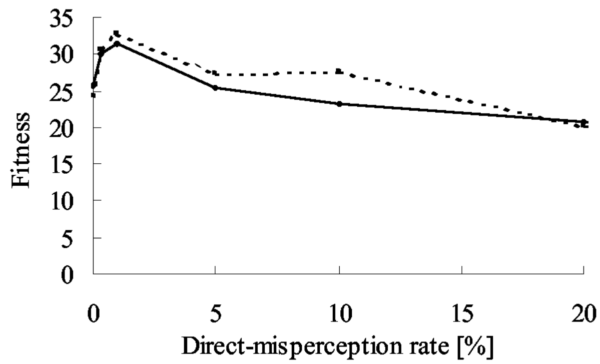
We introduced communication among agents in this experiment. Agents can obtain information by using their own visual sensors or by communicating with other agents. Misperception during communication was not investigated (indirect-misperception rate is 0%) in this experiment in order to grasp the effects of communication itself. We examined the influence of varying direct-misperception rate from 0% to 100%.

The results of the experiment are shown in Figure 9 and Figure 10, where they are compared with the result of the previous experiment. Figure 9 shows that the fitness was reduced by several percents by introducing communication among agents when direct-misperception rate is less than about 20%. The reason is supposed to be that the diversity of collective behavior was reduced owing to the share of the information concerning resources in the population. In this context, it is considered that communication can be unadaptive regardless of the truth of its content. It was also shown that introduction of accurate communication slightly increased the fitness when direct-misperception rate was 0%, though it is not easy to see from this figure.

Figure 10 shows the transition of the fitness. We see from this figure that the fitness fell with progress of time when direct-misperception rate was 1% and 10%. This means that communication propagated the information and reduced adaptive diversity of collective behavior generated by direct misperception which was investigated in the previous experiment. The reason of small decrease after 7000 turns in the case with 1% is supposed to be that the negative effect of misperception was accelerated by communication in latter turns.



(a)



(b)

Figure 9: Flow of the process.

Effects of indirect misperception

We investigated the effects of indirect misperception on fitness under the condition that direct-misperception rate was fixed at 0% and indirect-misperception rate was varied between 0% (receivers receive exactly what senders have sent) and 100% (receivers always misperceive what senders have sent).

The results of the experiment are shown in Figure 11. The fitness was increased about 1.5% compared with the case of accurate communication when indirect-misperception rate was less than 40%. This means that indirect misperception can prevent communication from decreasing the diversity in collective behavior, and can make communication adaptive.

Correlative effects of direct and indirect misperception

We investigated the fitness when direct-misperception rate was varied from 0% to 20%, and at the same time indirect- misperception rate was varied from 0% to 100%. The result of the experiment which applied direct misperception and indirect misperception simulta-

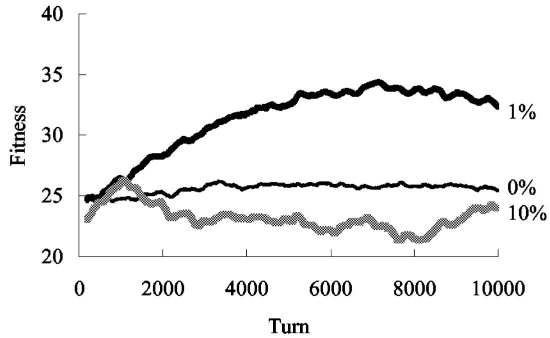


Figure 10: Flow of the process.

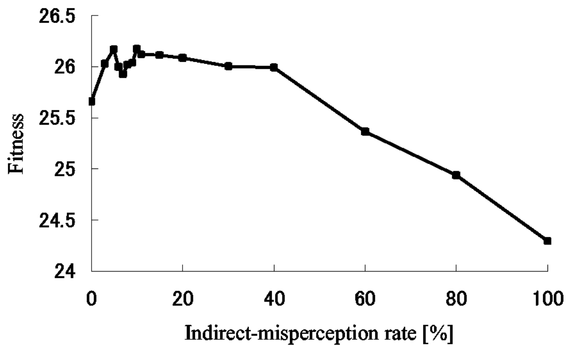


Figure 11: Flow of the process.

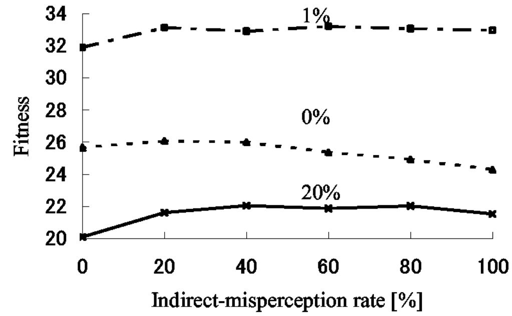


Figure 12: Flow of the process.

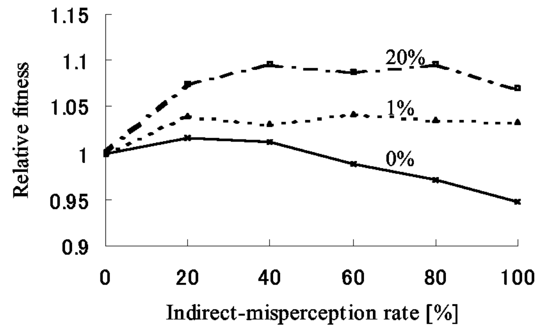


Figure 13: Flow of the process.

neously is shown in Figure 12. The fitness when direct-misperception rate was 1% and indirect-misperception rate was 20% is approximately 1.5% greater than the fitness when direct-misperception rate was 1% and agents have no communication (this case is shown in Figure 7). In other words, the results of the case when both direct and indirect misperception were allowed could be better than the case when either of the misperception was allowed. This fact implies that both of the misperception has mutually complementary effects on fitness of collective behavior.

Next, we investigated relative fitness when indirect-misperception rate was varied compared with the case that it was fixed at 0%. To do this, Figure 12 was converted to Fig 13, in which the fitness when indirect-misperception rate was 0% was normalized to 1 in each case. Figure 13 shows the tendency that the more the direct-misperception rate is, the larger the effect of indirect misperception becomes. This figure also shows a tendency that the optimal indirect-misperception rate becomes larger as direct-misperception rate increases, which is contrary to what we expected. Our understanding is as follows. When direct-misperception rate is large, communication makes more false information be shared in population and thus the fitness of population becomes low. Therefore, larger rate of indirect misperception is necessary for being optimal because it prevents population from sharing false information.

Effects of behavioral specificity

We examined the effects of misperception of information that prohibits a specific behavior in this experiment. For this purpose, poisons were introduced into the model as the source of prohibiting information. The information about poisons was also stored in the resource maps of the agents. Misperception might occur when obtaining the information about a poison, as is the case with the information about resources and empty spaces. Each agent didn't move to the poison if the agent had its information in its resource map. When an agent went into a cell where a poison existed, the fitness of the agent was reduced by the amount of the poison and at the same time, the amount of the poison became 0. The value of the fitness could be negative in this experiment. The poison would recover gradually in the same cell.

Some of the parameters were modified in this experiment as follows.

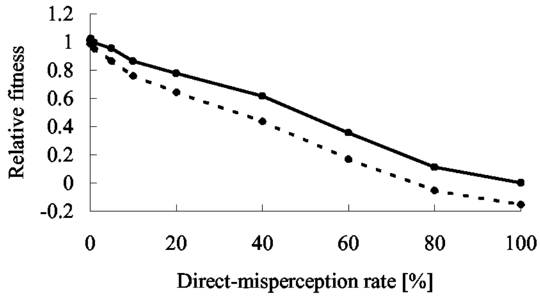


Figure 14: Flow of the process.

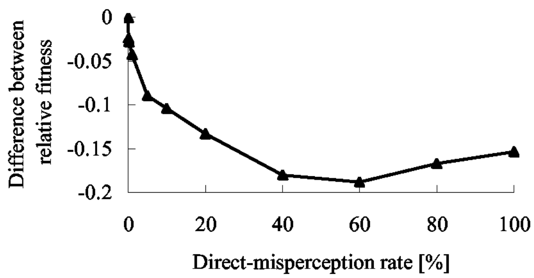


Figure 15: Flow of the process.

Field size:	30×30
Number of agents:	50
Number of poisons:	45
Maximum amount of each poison:	1

First, we investigated relative fitness when direct-misperception rate was varied from 0% to 100% compared with the case that it was fixed at 0%. Agents searched for resources by using their own visual sensors, and didn't communicate with other agents. Thus, only direct misperception could happen in this experiment. Figure 14 shows that introduction of poisons reduced the relative fitness to approximately 90%.

The fitness in the case without poisons has a peak when direct-misperception rate is around 0.2%, which shows the adaptive property of direct misperception though it is difficult to recognize it in this figure. On the other hand, the fitness in the case with poisons is the highest when indirect-misperception rate is 0%. In order to exclude the effect of the direct misperception regarding the resource, the former was subtracted from the latter. The result (Figure 15) is supposed to express approximately the effect of the direct misperception concerning the poisons. It has been shown that direct misperception has no adaptive property in the case that the objects were poisons.

Next, indirect misperception was examined. Figure 16 shows the difference between the case with poisons and the case without poisons when indirect misperception could occur. We see that the difference is larger than the one when direct misperception could occur. Figure 17 shows that direct misperception has also no adaptive property.

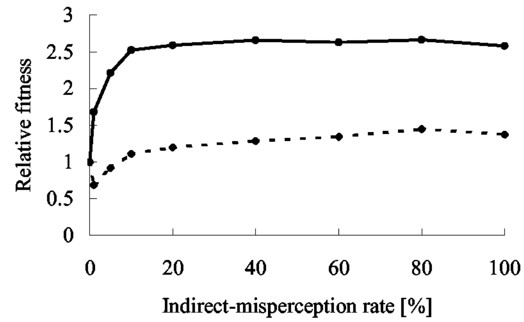


Figure 16: Flow of the process.

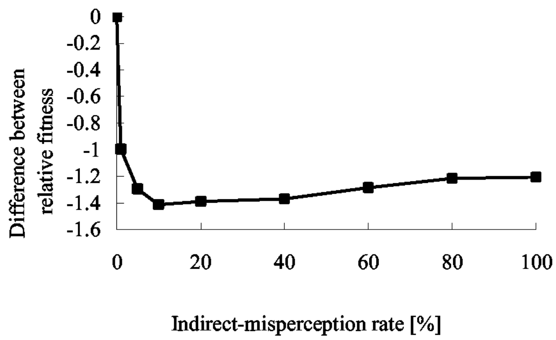


Figure 17: Flow of the process.

The difference between (food) resources and poisons is the specificity of the behaviors accelerated by the information about it. Possession of the information about a resource accelerates a specific behavior while possession of the information about a poison relatively accelerates broad range of behaviors except a specific behavior. Therefore, it can be said that this experiment supports the fourth property of the misperception in the hypothesis.

Conclusion

The role of random noise has been widely discussed in the field of complex systems and artificial life. For example, it is well known that introduction of noise improves the robustness of the cooperative relationships between players in the Iterated Prisoner's Dilemma game. This study focuses on the significant role of random noise at the level of perception system as the fundamental part of the cognition system.

In this paper, our hypothesis regarding the adaptive property of misperception was proposed, and simulation experiments were conducted so as to test it. The experimental results have shown quantitatively that misperception could increase diversity in behavior of agents, thus could be adaptive, or, to be more accurate, could contribute to adaptivity. (Hypothesis 1, 3). On the other hand, accurate communication could decrease a diversity of agent behavior, which might decrease fitness (Hypothesis 2). The paper has discussed a complex relationship between direct misperception and indirect misperception, besides detailed description of the simulation experiments. The last experiment has shown opposite results between the case with poison and the case without poison, which supports the hypothesis on behavioral specificity in adaptive property of misperception (Hypothesis 4).

The results of the experiments are deeply linked with the discussions in the field of memetics (Blackmore 1999). If we take meme-centered view, misperception originates in information itself (memes) while it has been assumed that the ability of the agents defines the misperception rate in our model. Dawkins argues that fidelity (replicate accurately), fecundity (easy to replicate), and longevity (last a long time) are the ways in which a meme is defined as successful (Dawkins 1976). The results of the experiments based on agent/gene-centered view in this paper are inconsistent with the first property (fidelity). It is a remarkable point that the inconsistency has been uncovered in the syntactic level and not in the semantic level (contents of the information) though there have been a variety of discussions over gene-meme competition (e.g. celibacy) (Bura 1994).

Also, in one sense, what the results of the experiments have shown is the antithesis of modern engineering. For example, the precision of sensors in robots has been improved without question. However, there is a possibility that improvement of sensors unexpectedly causes the decrement in total performance of distributed system of autonomous robots owing to the decrease in behavioral diversity in robots. At any rate, emergence of adaptive property of misperception in multi-robot systems depends on many factors including the sort of the task to be accomplished by robots and the ability of robots to communicate with other robots and to allocate jobs among robots. We are now developing a multi-robot system as a test bed for testing the hypothesis in the real world.

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