Indefiniteness of Observation for Spontaneous Generation of Robot's Behaviors

Jun Mukai Michita Imai
Yuichiro Anzai

Graduate School of Science and Technology, Keio University,
3-14-1 Hiyoshi, Kohoku-Ku Yokohama 223-8522, Japan +81-45-560-1070
{mukai,michita,anzai}@ayu.ics.keio.ac.jp

Abstract

In this paper, we propose Indefinite Observation Architecture(IOA) which enables robots to generate their own criteria for behaviors. In order for robots to act in everyday life, they have to achieve smooth communication with humans. But, the smooth communication is hard for robots, because various communication behaviors are required. In this paper, the variety of communication means that some kinds of behaviors can be appeared for the same situation. To achieve the various behaviors, we introduce Indefinite Observation. Indefinite Observation is a process which sometimes mistakes deliberately. By the mistake, robots change its criterion and variety of behaviors are achieved. We implement IOA for a simulated environment and confirm that IOA can generate various behaviors for robot. And, we also examine the effect of indefiniteness of Indefinite Observation. Then, the Indefinite Observation is necessary for variety, but the difference of indefiniteness affects little when the indefiniteness is greater than about 20%.

1 Introduction

Because of recent development of robotics, it is supposed that robots solve various tasks of everyday life in future. But there remains many problems for such robots. In this study, we deal with the variety of robot's behaviors in a human-robot communication.

In order for robots to play some roles in everyday life, it is necessary to achieve smooth communication between humans and robots. But, the communication between humans is too complex to describe all rules, and various communication behaviors can be appeared in the same situation. The generation of the variety is thought to be hard for robots.

Typically, communication robots are designed by the methods that employ many basic communication behaviors and rules for behaviors [1] [2] [3]. For example, supposed that there are two behaviors, "talking about the weather" and "greetings." To compose these behaviors, some if-then rules are required such that if the robot finds a human, then it says hello to the person and talks about the weather. But, since the rule-base system does not generate the other behavior in the same condition, it cannot deal with the variety of communication.

In this paper, the variety of communication does not means the capability to deal with many kinds of situations, but do that some kinds of communication behaviors can be appeared for the same sensor input. Thus, if the variety of communication is achieved, a robot sometimes says hello and talks about the weather but sometimes says hello and goes away. In order to achieve the variety, it is necessary to generate various criteria for behaviors selection.

For various criteria for behaviors, there are some requirements. The primary requirement, as we mentioned, is that robots react variously to the same sensor input. To achieve the various reaction, robots must change its criteria for behaviors regardless of its sensor input. However, if the change of criteria often occurs, it is thought that robots' behaviors become disordered. Since the disordered behaviors prevent the smooth communication, it is desirable that the change of criteria does not often occur in short term. In addition, the change of the criterion under the same sensor input does not mean that the criteria do not depend on the sensor input. If robots' behaviors are completely regardless of the sensor input, natural communications between persons and robots are not accomplished. To achieve the natural communication, the criteria for behaviors must reflect the sensor data. Therefore, various criteria for behaviors must achieves as follows.

1. changeability in the long term
2. stability in the short term
3. effect from the environment(sensor data)

To achieve these three requirements, we introduce "Indefinite Observation." This is a simple function which sometimes mistakes the observation result for input. Indefinite Observation is based on the measurement oriented model [4]. The measurement oriented model is a cellular-automata model which changes its state transition functions in the evolution of time because of the indefiniteness of observation. Although the measurement oriented model almost fulfills the three requirements, it cannot be applied to the robots. Since it is automata model and can only deal with truth values, it cannot be employed without any modification to deal with input from sensors and output to actuators.

In this paper, we design Indefinite Observation Architecture (IOA) which generates its own criteria for behaviors based on Indefinite Observation. In IOA, a criterion is frequently stable to generate stable behaviors in the short term. Also, IOA observes its own behaviors and others' behaviors to maintain the criteria in response to the environment. In particular, the observation sometimes mistakes by Indefinite Observation, to induce the change of the criterion for behaviors. These features of IOA satisfy the three requirements above.

This paper is organized as follows. Section 2 explains the overview of measurement oriented model, and discusses the relation between the measurement oriented model and our study. In section 3, an architecture based on Indefinite Observation is proposed. Section 4 explains the experimental environment and the results are discussed in section 5. Finally, we conclude and discuss future work in section 6.

2 Measurement Oriented Model

Measurement oriented model[4] is the basis of Indefinite Observation. In this section, we explain the model and discuss the relationship between the model and the variety of robots' behaviors.

Measurement oriented model is a cellular-automata model where state transition function is changed by measurement. The overview of the model is shown in Fig.1.

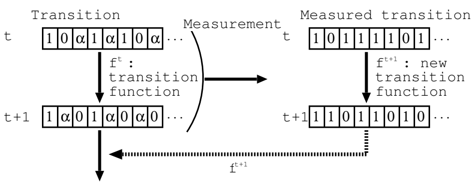

Figure 1: the outline of measurement oriented model

Conventional cellular-automata consist of automata arranged in line and a state transition function. An automaton transits to next state by the function. The arguments of the function for each automaton are the state of itself and the ones of neighbors. By iterating the transition of the states, some patterns of states are generated.

In the measurement oriented model, each transition is observed. The result of the measurement is used to construct a new state transition function for the next step. Moreover, the construction of the new function causes the situation that the next state of an automaton differs for the same input to the function, because the state transition function is not completely equals to the old one with the indefiniteness of the measurement.

The indefiniteness is attributed to the difference of the number of a state in the model. Each automaton has a value of $L_p = \{0, 1, \alpha\}$ but the measured value is in $L_b = \{0, 1\}$. Therefore, the measured transition does not completely correspond to the transition.

The relationship between the measurement oriented model and the variety of robots' behaviors is as follows. In the measurement oriented model, the state transition function can be changed in the evolution of time. Because patterns are generated according to the state transition function, automata generates various patterns when the rule for the construction of the next function is defined carefully. Some examples for various patterns are shown in [4].

On the other hand, the variety of robots' behaviors, our goal, is achieved by the three requirements: 1. changeability in the long term, 2. stability in the short term, 3. effects from the environment. The measurement oriented model seems to achieve the first and second requirements. But the effects from the environment are not considered. in other words, the input from sensors and the output into actuators are not considered in the model. The model cannot be applied into the generation of robots' behaviors directly.

The basis of the measurement oriented model is the indefiniteness of a measurement. To employ the features of the measurement oriented model, we design an Architecture based on Indefinite Observation.

3 IOA: Indefinite Observation Architecture

This paper proposes Indefinite Observation Architecture. The overview of IOA is shown in Fig. 2. IOA consists of four types of modules: Context, Observation, Output, and Order Function.

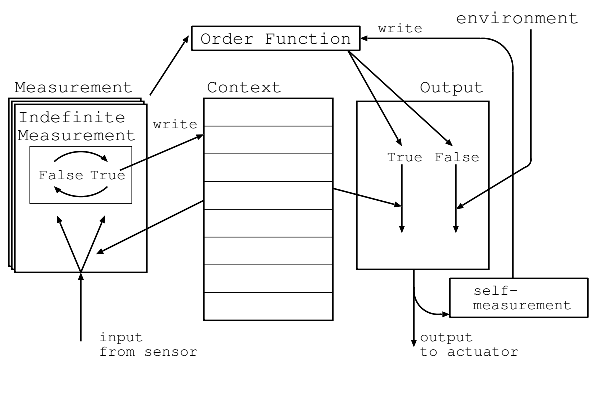

Figure 2: The outline of IOA

The process of the architecture is iteration between a behavior generation and a behavior observation. IOA generates a criterion for robot's behaviors based on the observation of the generated behaviors, and the robot generates its own behavior based on the criterion. The generated behaviors of the robot are observed by IOA. Moreover, the observation has the feature of Indefiniteness as we already explained in the section 2. Because of the indefiniteness of the observation of IOA, the criterion can slowly change and various behaviors are generated.

We explain each module in detail in the rest of this section.

3.1 Context Module and Observation Module

Context Module holds the sensor input which was determined as data within the criteria. Context Module is separated into some slots, where sensor input is stored. The contents of Context Module are used as a criterion for behaviors by both Observation and Output Module.

Observation Module determines whether the sensor input is within the criterion for behaviors or not, and transforms the input into a truth value $\{true, false\}$. This truth value is called as the "result of observation".

When sensor input comes, Observation Module randomly chooses a slot of Context Module and use the data in the slot as the criterion in this time. Then, Observation Module determine whether both of the sensor input and the criterion are similar or not. If they are similar data, the result of observation is *true*. Otherwise, the result is *false*.

Because the result of *true* means that the sensor input is within the criteria, Observation Module adds the sensor input in this time to Context Module. Since there are only a number of slots in Context Module, this addition must update one of the slots. The update process changes the contents of Context Module slowly.

In this paper, IOA has three Observation Modules. Two Observation Modules obtain sensor data for other robot's behaviors, and the other obtains sensor input for itself. The reason why IOA measures the behaviors of itself is that the criterion is not always valid in the next time by Indefinite Observation.

3.2 Indefinite Observation

In the measurement oriented model, the variety is obtained from the indefiniteness of measurement. That is, the result of measurement reflects the state but cannot correspond completely, because the number of states of measurement is smaller than that of state.

In IOA, this indefiniteness is achieved in Observation Module. Since the result of observation is a truth value, the result reflects the sensor input but cannot correspond completely. But, the indefiniteness in Observation Module is not enough yet.

The problem is that the contents of Context Module tend to converge on similar data. This is because only the sensor input similar to the contents of Context Module is added into Context Module. When the contents of Context Module completely converge on a same data, the result of observation cannot be changed in the evolution of time.

For the problem, "Indefinite Observation" is introduced into Observation Module. Indefinite Observation is a function which turns the truth value of observation result in probability P_i. By Indefinite Observation, other types of data are added into Context Module. Therefore, the indefiniteness of Observation is achieved.

Indefinite Observation seems to destroy the stability of Context Module. Of course, some of stability is lost, but the drastic change of Context Module is unlikely to occur because the normal result of Observation Module also updates Context Module. If the sensor input is not so often changed, the contents of Context Module is stable in normal.

3.3 Order Function and Output Module

Order Function takes three truth values which are the results of observation, and returns a truth value into Output Module.

The return value of Order Function is interpreted in Output Module. *True* means that the robot behaves stably, and *false* means that the robot behaves variously. When the return value is *true*, Output Module randomly chooses a slot of Context Module and outputs the data in the slot for the criterion. Otherwise, Output Module outputs the criterion generated from the environment.

Then, the characteristics of order function is described as the following table.

Table 1: The characteristics of order function

Inputs	$False$ output	$True$ output
FFF	diverging	systematization
FFT	original action	participation in a group
FTF	searching new context	keeping original context
FTT	leaving a group	keeping a group
TFF	original action	participation in a group
TFT	original action	participation in a group
TTF	leaving a group	keeping a group
TTT	destruction of context	converging

In this table, the inputs from FFF to TTT means three truth values. In this form, the first and third truth values are the results for other robots' behaviors. The second one is for itself. For example, when the inputs are FFT and the return value is $True$, it has a tendency to converge into another robot's behaviors, so it will join to a group of the robot.

Note that the outputted criterion does not always correspond to the meaning of the return value. When Context Module has various contents, the criterion chosen from Context Module can be dissimilar to another criterion in Context Module. Also, the criterion generated from the environment can be similar to criteria in Context Module.

3.4 change of Order Function

In measurement oriented model, the state transition function is changed by the measurement. Similarly, the Order Function is changed by observation of the output criterion. We explain this process in detail.

The total output from Output Module is checked by a Observation Module. This check is called as "self-observation." And, the result of self-observation is compared with the return value of Order Function in this time. If there is inconsistency between the return value and result of self-observation, the return value of Order Function in this time is turned. Fig. 3 shows the outline of this process.

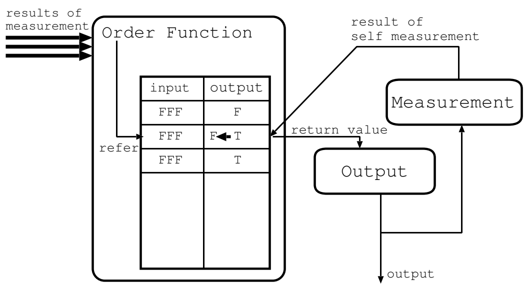

Figure 3: The Updating Process of Order Function

There are two reasons why there can be inconsistent. First reason is the variety of Context Module. When Context Module keeps various criteria, the criterion chosen from Context Module can be dissimilar to the criterion of self-observation. Also, the criterion from the environment can be similar to the criterion of self-observation.

The second reason is the Indefinite Measurement of self-measurement. Because the self-measurement also has the Indefinite Measurement, the result can be turned in a probability P_i. Then, originally consistent result can become inconsistent.

3.5 behavior of IOA

The stability of IOA is determined by the return value of Order Function. When the return value is *true*, the contents of Context Module tend to converge on similar data and the outputted criterion is stable.

But, the return value can be changed into *false* for some reasons. Then, the outputted criterion is disordered. If there are few *false* in Order Function, the return value can be *true* and the criterion can become stable. But, the return value for the results of measurement remains *false*. Therefore, the number of *false* in Order Function is increasing when the criterion is stable.

If there are many *false* in Order Function, it returns only *false*. During *false* return value, the contents of Context Module are rewritten by Indefinite Observation. When Context Module has various data, the return value tends to be changed into *true*. Then, the contents of Context Module converge on a type of data which can be different from the older one.

By the process described above, the criterion is changed in a short term. But, the criterion is stable in other short terms. Therefore, the variety of criterion is achieved by IOA.

4 Experiment

In order to evaluate the characteristic of IOA, we examine it by the simulation. In this section, we explain the experimental environment.

4.1 robots

In this paper, robots interact with each other by behaviors only. In other words, robots do not send any message, but are affected by their behaviors. Many multi-robot systems have the approach to construct cooperative works by passing messages explicitly [5] [6]. But, on the assumption that robots behave in everyday life, the premise that robots must exchange messages cannot always be applied. Then, we have assumption that robots do not exchange any messages but robots' action are affected by measurement for other robots' action. Robots have various kind of actions. To make the problem simple, we restrict the robots action to the change of direction. Robots can only change their own directions and cannot treat with position and so on.

Also, there are some alternatives for the criteria for robots' behaviors. In this study, the criteria is also restricted to color. We have a premise that each robot obtains colors of all the direction. Robots change their direction in order to face to the criteria colors.

4.2 experimental environment

We develop an experimental environment. The overview of experimental environment is shown in Fig.4. The characteristics of environment are as follows.

The shape of the environment is a circle. There are 10 robots randomly put in this circle. The boundary of the circle has some colors, and each color has equal width. Each robot observes the behaviors of the nearest two robots.

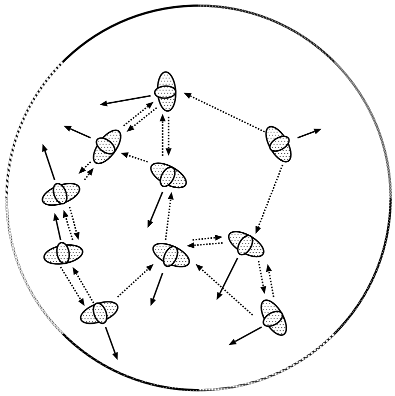

Figure 4: experimental environment

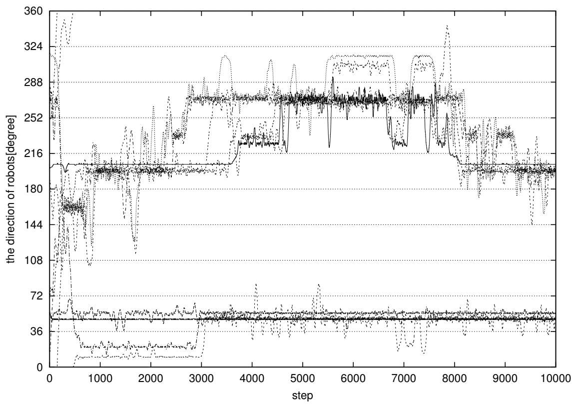

Figure 5: transitions of robots' directions in normal environment

4.3 the method of evaluations

We examine the behaviors of IOA in the environment described above. In this paper, we not only confirm the behaviors of IOA, but also evaluate the effect of Indefinite Observation. For this evaluation, we experiment for the parameter P_i.

For evaluation, two values are introduced. First, the short term stability S_s is the mean of the short term (20 steps) moving width. The more is this value, the more unstable are behaviors in the short term. Second, the long term stability S_l is the standard deviation for total moving width of one test. The more is this value, the more changeable is the long term behavior. Therefore, in order to achieve the various behavior, it is desirable that the S_s becomes low and the S_l becomes high.

We have 100 tests for each parameter, and calculate the mean value for both S_s and S_l.

5 Experimental Results

5.1 typical result

First, the typical result of a test for $P_i = 20[\%]$ is shown in Fig.5.

This figure shows the transitions of robots' directions in the environment described above. The horizontal axis means time (in steps), and the vertical axis means the normalized direction of a robot, i.e. the direction of the wall at which the robot looks. And, the horizontal grids means the boundary of one color of the wall.

In this result, major of robots in each step seems to be stable normally. They do not change their own directions. But, their directions are drastically changed in some time. It seems that the robots' directions are stable in the short term and changeable in the long term.

5.2 effect of indefiniteness

In order to evaluate the effect of Indefinite Observation, we execute 100 tests for each P_i and calculate the means for the two values, short and long term stability. The results are shown in Fig. 6 and Fig. 7.

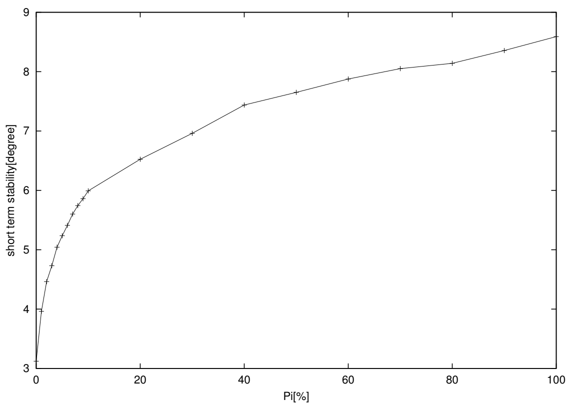

Figure 6: Short Term Stability

In these figures, the horizontal axis means the P_i in percentile. In Fig.6, the vertical axis means of the mean of moving width in short term. In Fig.7, the vertical axis means the standard deviation of total movement.

The outlines of these figures are very similar. When the $P_i = 0[\%]$, the value is very low. Otherwise, there are not so different between P_i.

When P_i equals to 0%, there are no Indefinite Observation. It is considered that Context Module of each robot converges into single value so that robots cannot interact to each other. On the other hand, if P_i is greater than 20%, the effect of the difference of P_i becomes very low. By this result, it is considered to be more essential for robots to keep on interacting to each other than be able to add other data into Context Module more often.

6 Conclusion

In this paper, we propose IOA: a system that robots generate various criteria for behaviors from observing their

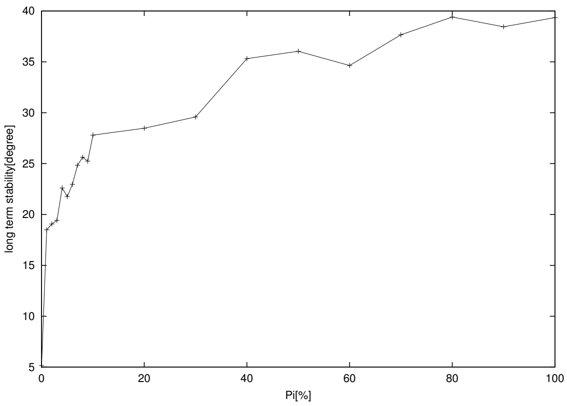

Figure 7: Long Term Stability

own behaviors. The main feature of IOA is Indefinite Observation, which is deliberate mistake of Observation Module in probability P_i. By Indefinite Observation, IOA can obtain a new criterion without spoiling the stability.

We test the behaviors of IOA with simulation and confirm that robots generate various behaviors. Furthermore, we examine the effect of Indefinite Observation. As a result, although Indefinite Observation is essential for variety, but the effect of the difference of P_i is little when the P_i is greater than about 20%.

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