A Robot Organizing Purposive Behavior by Itself

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Abstract

For studying the mechanism of the brain, so called "synthetic approach" is effective. Synthetic approach is to conjecture the mechanism of the target through constructing its model. We have constructed some twenty models of the brain for this study. In this article, we describe one of them which we constructed recently. The model includes abilities of perception, memory, and action. To have these three abilities enables the model to realize highly intellectual behavior or self-organizing ability that cannot be realized by a model having just one ability. We realized the model in the form of a robot which organizes purposive behavior by itself. This robot forms effective behavioral patterns to achieve the purpose through trial and error.

1 Introduction

"Synthetic approach" is a common approach to the mechanism of the brain in the Engineering field. In this approach, first, function of the brain is separated into various kinds of subfunction, then a model is constructed for each one based on physiological knowledge and some hypotheses. Although we have constructed some models for perception, memory, and action separately, in this article, we describe a model of total function which includes these three subfunctions.

A human being is born with receptors (i.e. eyes and ears) and effectors (i.e. hands and legs). With the effectors, he makes actions in the outer world, and with the receptors, he gathers information from the outer world. Through these interactions, a human being can build in his brain "world image", that is, the model for objects and phenomena in the outer world. With this world image, human being can recall the past, make consideration, and make purposive behavior. Therefore, in order to study the brain function, it is natural to construct a model which includes the abilities of perception, memory, and action.

Since each subsystem is still under investigation at present, we cannot construct a complete model. Consequently we simplify the outer world and restrict the function of this system. As long as the simplification doesn't lose the generality, to construct the system may be instructive. The model is realized in the form of a robot. The robot observes the outer world with several sensors, and learns by trial and error to produce purpose oriented behavior by combining elementary actions. The purpose assumed here is to tell between enemy and prey, and to beat the former and catch the latter.

Before explaining the robot, we describe Associatron which is used as the brain of the robot.

2 Associatron

Associatron which was proposed by one of the authors is a neural network model for associative memory. The items to be memorized are represented as n-dimensional vectors, whose elements take values -1,0 or 1:

$$\boldsymbol{x}^{(\boldsymbol{p})} = (x_1^{(p)}, x_2^{(p)}, \cdots, x_n^{(p)}), \tag{1}$$

where p is the index of the items. x_i corresponds to the state of neuron i and the value 1 or -1 represents that the cell gets excited. Associatron memorizes the $\boldsymbol{x}^{(\boldsymbol{p})}$ as the sum of the auto-correlation matrices of the vectors, that is:

$$\boldsymbol{M} = \sum_{p=1}^{k} \boldsymbol{x}^{(\boldsymbol{p})^t} \boldsymbol{x}^{(\boldsymbol{p})}, \tag{2}$$

where k is the number of the items Associatron memorizes, and t designates transportation. Each element of the matrix corresponds to the strength of the synaptic connection. Memorized vectors are recalled according to the following equation, using an n-dimensional input vector $\boldsymbol{y}$:

$$\boldsymbol{z} = \Phi_0(\boldsymbol{y}\Phi_0(\boldsymbol{M})), \tag{3}$$

where $\Phi_0(u)$ is a threshold function,defined as:

$$\Phi_0(u) = \begin{cases} -1 & u < 0, \\ \ \ 0 & u = 0, \\ \ \ 1 & u > 0. \end{cases} \tag{4}$$

When this function is applied for matrices or vectors, the above operation is carried out for each element of matrices or vectors.

If some elements of the input vector $\boldsymbol{y}$ are equal to those of $\boldsymbol{x}^{(r)}$ and the other elements are 0, then the output vector $\boldsymbol{z}$ is expected to be equal to or similar to $\boldsymbol{x}^{(r)}$. Thus, Associatron memorizes the patterns as the form of a matrix and recall each of them from only a part of the pattern.

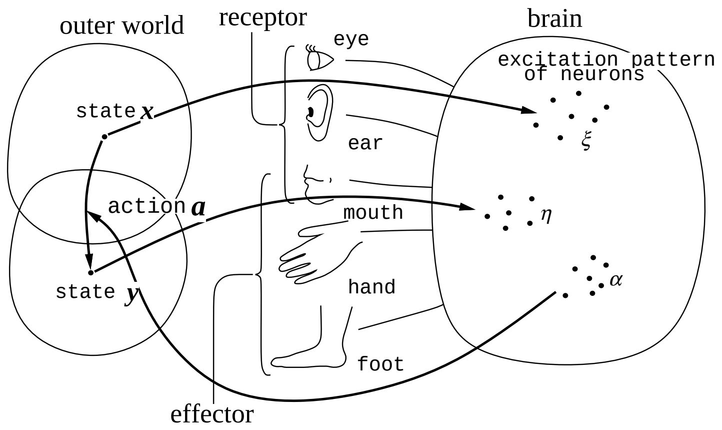

Figure 1: Perception in the brain

3 Constructing World Image

We considered the process how human beings obtain the knowledge of the outer world as follows.

Fig1 shows schematically our principle. It is assumed that, when the receptor observes the outer world in state $\boldsymbol{x}$, a pattern of exciting neurons $\boldsymbol{\xi}$ appears in the brain. On the other hand, in order to make an action $\boldsymbol{a}$, also a pattern of exciting neurons $\boldsymbol{\alpha}$ must appear in the brain. Consider the case where action $\boldsymbol{a}$ causes the transition from state $\boldsymbol{x}$ to $\boldsymbol{y}$. $\boldsymbol{y}$ is observed with the receptor, and causes the pattern $\boldsymbol{\eta}$. If we consider the outer world as an automaton, the transition $\boldsymbol{x} \xrightarrow{\boldsymbol{a}} \boldsymbol{y}$ in the outer world is mapped into the brain in the form of $\boldsymbol{\xi} \xrightarrow{\boldsymbol{\alpha}} \boldsymbol{\eta}$ using effector and receptor. The system acts at random to get the knowledge and memorizes many kinds of $\boldsymbol{\xi}' \xrightarrow{\boldsymbol{\alpha}'} \boldsymbol{\eta}'$. Thus the important brain function called "universal simulator" is realized.

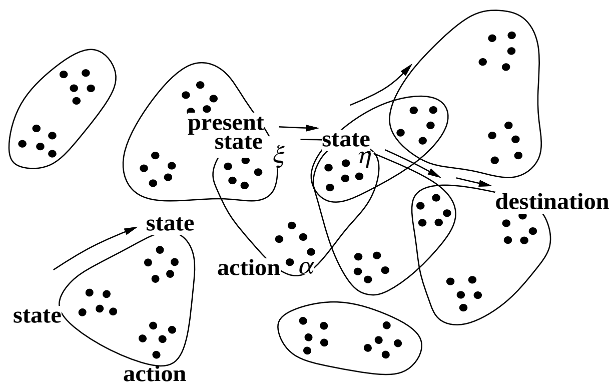

Figure 2: Formation of "world image"

If the system memorizes many sets of patterns through some interactions with the outer world, it appears such structure of memorization as shown in Fig2. We call this structure "world image". World image is the model of the part of the outer world which a human being can observe with its receptors. The sets which have only 2 patterns, that do not include the pattern $\boldsymbol{\alpha}'$, mean that the outer world changes its state without any action of the effector. We can understand these cases as autonomous transition of an automaton. In the figure, there are some chains of sets of patterns. Tracing the chain, the system can "think". This means it can image how to accomplish the purpose even if it has not experienced the whole sequence.

4 Implementation Using Associatron

In this section, we describe how we implemented above concept with Associatron.

Let us consider that the set of neurons in Fig2 corresponds to $\boldsymbol{x}$ in Associatron. For example, when Associatron memorizing sets of patterns $\boldsymbol{\xi}$, $\boldsymbol{\eta}$, and $\boldsymbol{\alpha}$, we impose vector $\boldsymbol{x}$ on Associatron.

$$\boldsymbol{x} = (0, \cdots, 0, \overbrace{1, -1, 1, 1, -1,}^{\boldsymbol{\xi}} 0, \cdots, 0, \overbrace{1, 1, -1, -1,}^{\boldsymbol{\alpha}} 0, 0, \overbrace{-1, -1, 1, -1,}^{\boldsymbol{\eta}} 0, \cdots, 0) \qquad (5)$$

Thus, the structure of memorization of Fig2 is realized in Associatron.

Here, impressing present state $\boldsymbol{\xi}$ to Associatron, it recalls the action $\boldsymbol{\alpha}$ which causes the transition $\boldsymbol{\xi} \longrightarrow \boldsymbol{\eta}$. Associatron traces a knowledge chain by repeating this process [2]. The cases that the chain contains branches is discussed in [3].

Moreover, putting some stimuli to the neuron which corresponds to the destination state, Associatron tends to trace the chain which leads to the state [2].

5 A Robot Organizes The Purposive Behavior

In order to investigate the effect of the concept mentioned above, we constructed a robot which obtains purposive behavior by itself.

Before describing the robot, consider the following experimental results of field of psychology. At the situation that there were some bananas on a high shelf which a chimpanzee cannot reach, the chimpanzee brought a box and stand on it to take the bananas. Since the chimpanzee had not experienced such situation, it can be regarded as following that it formed the purposive behavior by combining previously obtained knowledge. The knowledge includes, for example,"banana is delicious", "it can move boxes", and "it can reach higher position by standing on the box". We tried to make a robot which has the simple thinking process as the chimpanzee. The robot is shown in Fig3.

We set a simplified world where there are two kinds of targets: One is a "prey" and the other is an "enemy". The purpose of the robot is to beat the "enemy" and to catch the "prey".

Although the robot has the ability to do the purposive behavior, it is not taught how to do. As we described above, the robot makes random actions, and consequently constructs the world image. After enough learning, the robot attains the purposive behavior utilizing the world image.

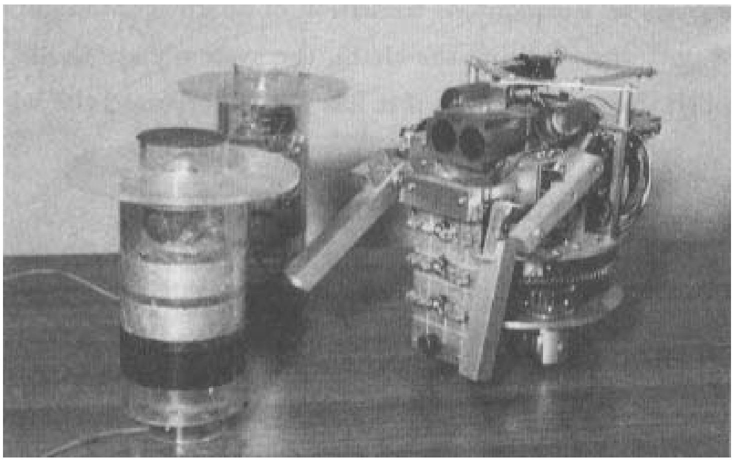

Figure 3: Robot and Targets

The robot can make the following basic actions;

1. Turning the body.
2. Going straight forward.
3. Stretching out the right arm in front.
4. Raising the right arm overhead.
5. Stretching out the left arm in front.
6. Raising the left arm overhead.

And also the robot has the following sensors;

1. "Eyes" (optical sensors).
2. Supersonic sensors (which tell that the target is near to the robot).
3. Switch (which tells the shape of the target).
4. "Ears" (sound sensors).
5. Touch sensors on the breast (which tell that it is touching the target).
6. Touch sensors on the back (which tell whether the target is prey or enemy).

The patterns corresponding to each action and sensor are fixed previously.

It should be noticed that receptors #4 and #6 cause instinctive stimulation to the robot. They tell the robot satisfaction and unpleasantness. Satisfaction is obtained when the robot catches the prey or beats the enemy. But if it catches the enemy, then the robot becomes unpleasant. The robot keeps on making actions until it is “satisfied”.

The robot “thinks” how to accomplish the purpose when it cannot trace the sequence, here it acts at random to get knowledge. As the robot stores more knowledge, it comes to make effective behavior to accomplish its purpose. After learning, the knowledge are stored in the brain of the robot. Here, it comes to behave as follows, first searches the target then approaches to it, second if it is prey, takes it, or if it is enemy beats it.

If we “help” the robot while it is learning, then it comes to learn easily. The help we make are, for example, to put the robot near the object, or to make it touch the object. This process is very similar to what a mother does for her baby.

6 Conclusion

This robot learns how to make the purposive behavior through the interaction with the outer world. At first, the robot makes action at random, then it stores the knowledge to construct world image. With this world image, the robot comes to make purposive behavior. Through this article, we proposed one method for an robot with receptor, effector and “brain” to self-organize purposive behavior. Apparently both of the outer world and the behavior of the robot are simplified. However, we believe that the model retains the essence. This article will give instructive suggestions of the application of associative memory and neural networks.

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