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From Bacteria, a Consideration of the Evolution of Neural Network

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Abstract: The neural network proposed in this paper hierarchically processes time series data and has the function which becomes the basis of intellectual behavior of not only bacteria but also evolved animals. At first, time series data are divided into sequences of subsequences in which the same element does not appear multiple times. The neural network that recognizes/generates the obtained subsequence is familiar to basic behavior of nerve cells and is called a Basic Unit. General time series data have a hierarchical structure. The lowest level is the sequence of the subsequence obtained as a result of division. A neural network composed of hierarchically connected Basic Units processes time series data. Hierarchical processing is performed according to the context structure of time series data. The place where the Basic Units are activated moves from upper layer to lower layer or in the opposite direction as processing progresses. It is possible to predict the next processing by using the contextual position of the current executing process. There is a plurality of neural networks which process time series data according to the category of time series data. Isomorphism between neural networks brings about isomorphism of context structure of processing process. The behavior of mirror neurons is explained using the interaction between isomorphic neural networks.

Key words: Time series data, hierarchical processing, context structure, prediction, mirror neuron.

1. Introduction

Even animals like bacteria, which is the early stage of evolution, have to take the following actions to live. They move according to the sensation of light or smell, approaching objects that may be food. If by sight or tactile sense they judge the subject is food, they will eat the subject. If the subject resists their behavior, they will fight or avoid the subject. Aside from whether the behavior of this animal is evaluated as an intelligent behavior, the pair of the object state obtained by the animal by the sensory organ and the object state changed by the exercise organ is "world" for the animal.

(I) The world is everything that is the case.

(II) The world is the totality of facts, not of things.

- Ludwig Wittgenstein
- Tractatus Logico-Philosophiicus [1]

It seems possible to imitate the behavior of the animals described above by combining sensors and logic ICs and the number of logic elements used may not be very different from the sum of nerve cells of insect and zooplankton. Animals evolve to having a more complex structure beyond the example above and gain higher functionality adapting to various environments "world".

There are many ways of thinking that Evolution is whether the ability acquired by chance in the animal's life the result of being taken over by interspecific culling or animal's life has a willingness to improve ability. In any case, the essential ability of animals in the next evolutionary stages of the aforementioned animals is the action of getting food. That is, it is an operation to extend the arm or the like based on the distance judgment to the target object, open the hand when the arm extends to an appropriate position, and grasp the target just before contacting.

These actions are performed based on the combination of information from sensory organs of the animal's own muscle or joint and information from

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objects such as visual and tactile sensations. Because the movement of the arm and the movement of the fingers can be done independently, the series of movements is made only by hierarchically connecting both movements.

A method called Bayesian hierarchical prediction has been successful in executing the learning process of the above animals in computers. This method consists of repetition of statistical processing around Bayes' theorem. D. C. Dennet [2] said that the details of neural implementation of such hierarchical predictive coding networks are obscure, but they do not seem out of reach. But he also refers to skeptical opinions about his view. Skepticism is that the predictive generation algorithm itself was created by the programmer in favor of creating a profit. Although the behavior of animals in the initial stage of evolution mentioned in the first example seems to be realized by sensors and logic ICs, to mimic the behavior of animals at the next stage of evolution an algorithm based on fast hardware is used. This method is incompatible with the idea that the process of evolution of an animal's cranial nervous system is a build-up of partial improvement.

In this paper, to solve this leap, the context structure inherent in time series data is taken up. Since the context structure well corresponds to the hierarchical connection of the neural network, the presented neural network has hierarchical processing and prediction function in keeping with the knowledge of neuroscience based on the Hebb rule. The representation of the neural network is generalized and can describe the behavior of a more intelligent animal. The behavior of mirror neurons will be explained by the behavior of the presented neural network, and the relation with language will be mentioned.

2. Dividing Time Series Data and Reflecting on the Neural Network

2.1 World Drawn by Time Series Data

It is the language that comes to mind first as time series data. Dennett states as follows [2].

Our tongues can only consistently get around a limited inventory of separate speech sounds, and our ears can only detect acoustic distinctions down to a certain level of subtlety.

That is, the idea is that time series data consisting of a combination of finite kinds of elements commonly used by listeners and speakers are a means of communication.

This idea let extend to a wider world. In addition to speech listening and pronunciation, the resolution of our five senses (different for each person and fluctuating) is limited, so the object of recognition can be interpreted as time series data consisting of a combination of finite kinds of elements.

Furthermore, the accuracy of our action is often inaccurate as well as sensation. Most of the actions are done while feeding back the sensation of joints and muscular loads, but that sensation is not always accurate as mentioned above. Therefore, our action can also be interpreted as time series data consisting of a combination of finite kinds of elements.

The hierarchical structure of time series data is related not only to the movement of the body but also to the recognition of the columns of objects or patterns. For example, when five coins are shown, we recognize that the total number is 5 from the sum of 3 and 2 coins. My surname Yanagawa is two characters in kanji, but Japanese people recognize by a combination of three elements as shown in the Fig. 1.

We find a hierarchical combination of known subsequences from given time series data and use the subsequences for both recognition and action.

Let us have a sight of the beach at dusk. Waves repeat entering and leaving. Your five senses follow the change in sound and shape. You estimate the type of bird from birds singing (some types have a context with

Fig. 1 An example in which even two characters of kanji are recognized as three divisions.

twitter). The sun is about to sink on the horizon with the collapse of the letters written casually on the sand. Your thoughts may start with memories of events that happened that day, predictions for the evening and tomorrow coming soon, even the seasonal changes and the future of the earth. You are involved in these scenes by accepting the synthesis of time series data of various cycles. That is your “world”.

2.2 Dividing Time Series Data

Time series data composed of finite kinds of elements can be divided into a plurality of subsequences in which the same element does not appear plural times. For simplicity, it is assumed that kind of the elements of the time series data are 10 from 0 to 9. Fig. 2 shows an example of dividing time series data into five subsequences. An element that already exists in the time series data is a division point (the beginning of the next subsequence).

The division procedure will be described in more detail as follows.

(1) Let the top element be the beginning of the first subsequence.

In the example given, the first element is c_5, and then c_6, c_3, c_4 and subsequences are added. When an element satisfying the following condition appears, the element is regarded as the head of a new subsequence and the given time series data are divided.

(2) For the subsequences obtained by above procedure (1) repeat the same process and continue the split.

(3) If the maximum length is defined in the subsequence, the following data are added as elements of the new subsequence after the subsequence which has reached the maximum length. The partial sequences divided by the above procedure are called the basic sequence. It is clear that the same procedure can be applied to time series data arranged arbitrarily elements.

By adopting each basic sequence as elements of time series data of the upper hierarchy, the context structure is as shown in Fig. 3. The actions of the arms and hands when getting the food described in the previous chapter can be expressed by such a hierarchical expression. However, movement may be clumsy as it is.

The process of recognizing words that are known from consecutive phoneme sequences such as spoken sentences is similar to the process of dividing common time series data into basic sequences. Although the basic sequence and the word dictionary are not perfectly identical, the following describes that the process of dividing the time series data has high affinity with the operation of the neural network.

In Fig. 4, the first input c_5 is received, the elements connected to the input c_5 are activated. Subsequently, when c_6 is received, the elements connected to the input c_6 are activated, but among them, the set of elements having the high activity and the initiative is included in the set of elements activated by the previous input c_5. The same is done for subsequent elements c_3 and c_4.

The behavior that an element is activated only in a specific time series data is not an intentionally designed operation at the beginning. Since the inputs are sparsely connected to each element and there are various aspects to the connection, it is conceivable that only a few elements remain active until the end of the time series data as a result. This model not only adapts to neural circuits, may give hints for the future design of electronic circuits.

$$c_5c_6c_3c_4c_5c_6c_4c_9c_2c_5c_6c_4c_3c_0c_3c_9c_4c_3c_3$$

$$\Downarrow$$

$$c_5c_6c_3c_4 \mid c_5c_6c_4c_9c_2 \mid c_5c_6c_4c_3c_0c \mid {}_3c_9c_4c_3 \mid c_3$$

Fig. 2 Any time-series data has hierarchic structure.

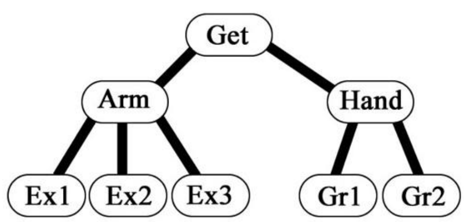

Fig. 3 Context structure of the time series data shown in Fig. 2.

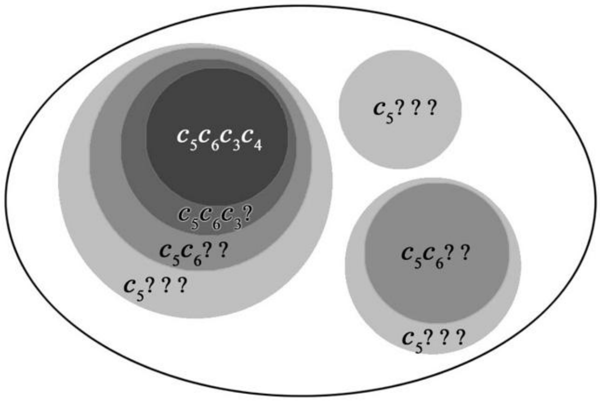

Fig. 4 As the time series data are received, the activated area is specified.

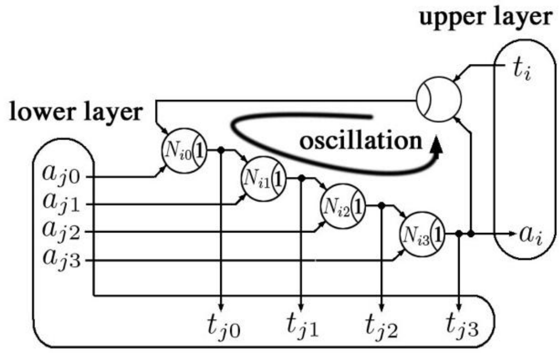

Fig. 5 Local oscillation and two-way communication among hierarchy of neural networks.

The element which is still activated at the end of the subsequence is the recognition result, but the element may be present in multiple regions. For example, when the time series data BACH is given, in the area activated by music the element corresponds to Johan Sebastian Bach of the great composer, and in the area activated by sports the element corresponds to Tomas Bach who is president of International Olympic Committee. For German speaking people, the element corresponds to the word Bach which has the same meaning as English brook.

The fact that one word has various meanings depending on the situation of the recipient suggests that the inputs of the neural network are sparsely connected to a wide area.

2.3 Realization by Neural Network

The neural network showing the operation conceptual diagram in Fig. 5 is called a Basic Unit and recognizes and generates the basic sequence. The Basic Unit is a circuit in which elements corresponding to AND circuits are connected in series. In Fig. 5, the number of elements is set to 4 for simplicity, but the number of elements is determined by the result of sparse connection between the elements and I/O signals. If there is an element that has been activated until it receives the end of the basic sequence, the connection between the elements is the connection that is useful for processing the basic sequence. Probably the number will be 1 to at most 10.

As a special case, if the number of connections is 1, the Basic Unit is equivalent to a simple transmission element. The behavior of the “early stage animals of evolution with roots in bacteria” in Chapter 1 can be imitated by the neural network using the simple units.

In other words, the difference between animals at the early stage of evolution and animals at the next stage that can acquire food using hands etc. can be attributed only to the problem of complexity.

The core operation of the Basic Unit is described below.

(1) Recognize a specific basic sequence in time series data. The output a_i at the end of the element corresponding to the AND circuit connected in series is the recognition result.

(2) After learning the basic sequence, it has the function of the oscillator by positive feedback. The circuit is activated by the t_i signal, and generates the learned basic sequence.

(3) After completing the processing of the basic sequence, the Basic Unit activates the Basic Unit which performs the following processing and lowers own activity level.

The acceptance of the time series data received from the lower layer is transmitted to the upper layer, and the signal from the upper layer causes the local oscillation function and generates the time series data to the lower layer. That is, it plays the role of a parallel/serial interconverter.

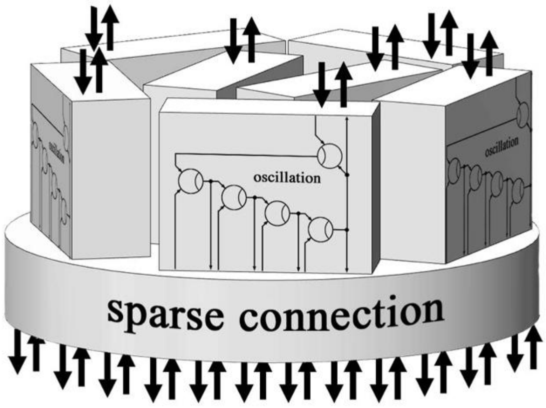

Fig. 6 A diagram of one layer containing seven Basic Units.

Since the basic sequence is obtained by dividing general time series data, arbitrary time series data can be processed by adopting the base sequence as an element of new upper layer time series data. Fig. 6 is a diagram of one layer containing seven Basic Units.

Although there are various methods for realizing the above operation [3], it is necessary to continue to improve according to the knowledge of neuroscience avoiding closely concerning to the operation of the existing hardware.

3. Prediction and Analogy

Fig. 7 is an illustration of the transition of activity levels of the eight Basic Units in the neural network during time series data processing.

Here, t_0, t_1, ... represent discrete time. The unit U_{10} activated by U_{00} at time t_0 activates U_{01} and U_{02} and generates time series data at times t_1 and t_2. Upon completion of generation, U_{10} activates U_{20} to prepare for processing after time t_3. It is shown that the context structure of processing is useful for predicating actions to be taken [4].

The meaning of the unit activated earlier in several steps may be compared to "stance" for behavior in generating time series data. Every time one procedure is completed, the action to be performed next will become clearer. The process of reaching the target can be regarded as finding details as the distant view approaches.

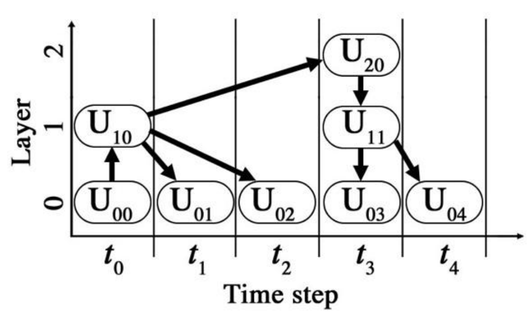

Fig. 7 A transition of activity levels of Basic Units.

On the other hand, details of the process that finished are gradually lost as past events, the context in which the process was placed remains in the time series, and finally its existence is buried in new data.

Places with the most active Basic Units move according to the processing of time series data. It seems not impossible to correspond this moving to changes in our "consciousness".

With experiences and learning progress, the context of time series data will become deeper and wider. Thus "consciousness" will spread to the spacetime beyond own existence like at the scene of the beach described in Section 2.1.

The meaning of time series data differs depending on which activation area the time series data are recognized like the character string "BACH" mentioned as an example in Section 2.2.

Let N_0 and N_1 be neural networks for processing time series data, and U_a and U_b be the Basic Units contained in N_0.

Let $U_a R U_b$ denote the relationship R between U_a and U_b.

Let f be a mapping from N_0 to N_1 and define N_1 to be homomorphic with N_0 when $f(U_a)\ R\ f(U_b)$ holds for elements $f(U_a)$ and $f(U_b)$ of N_1. The inverse mapping f^{1} can be defined similarly. Category theory will be suitable for the above description.

An example in which the framework of the law is preserved even if elements and action types are replaced is familiar to the relationship between heat transfer and electric current.

In our daily life, when thinking or explaining about not only weather but also movement of politics etc., it is common to use analogy of the movement of certain kinds of things. By incorporating references to the context structure of other neural networks to processing time series data, prediction and search efficiency are improved.

Suppose there are two similar neural networks. If a time series data is given, each neural network is activated in the same way due to similarity. If there are some connections between the neural networks, it seems possible to assume that the side that does not receive the time series data is also activated and both will change state along the same context.

The above assumption helps to explain the behavior of mirror neurons that have an impression of something magical behavior. Mirror neuron work has been confirmed in various experiments including monkey imitating people.

Marco Iacoboni explained as follows:

If a cell discharged more vigorously while the monkey was grasping the food in order to eat, that same cell discharged more vigorously while the monkey was observing the human experimenter grasping the food in order to eat [5].

In Fig. 8, when the monkey extends hand H_m to food, neural network N_0 controlling H_m and N_1 monitoring the motion of H_m are activated at the same time. Every time the monkey moves own hand, the time series data of the image showing the movement of the hand are learned in N_1. Next, when the experimenter in front of the monkey extends hand H_p to food, N_2 is activated and receives time series data of the image showing the movement of the hand. Since this data is similar to the movement of the monkey's own hand, if there is a connection from N_2 to N_1 as in the above assumption, N_1 is also activated. Furthermore, since N_1 and N_0 are areas that are always activated together as a movement of a monkey, N_0 is also considered to be activated by being inspired by movement of the hand of the experimenter.

In this explanation of the operation of the mirror neuron, the movement of the arm is taken up, but the same idea is established even if sound is adopted. A monkey who heard a fellow's monkey can utter imitation of that fellow's monkey. If both the speaker and the listener recognize that a word indicating food is present in the time series data of the voice and that word indicates an object with which the hand is held, communication is established. That is a primitive step of language [6].

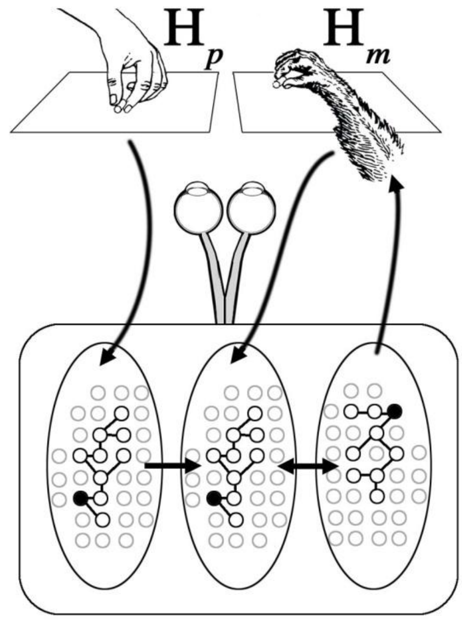

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Fig. 8 Conceptual diagram of behaviors of mirror neurons.

5. Conclusions

When considering the intelligence of animals, it is impossible to talk without relation to the body. In discussions based on the findings of neuroscience, it is not necessary to refer to a program executed by a computer or devices for high-speed processing such as GPU etc.

However, it seems to make sense to go back to the bacterial level behavior to think about systems that operate beyond the concept of existing hardware. The stance to existing hardware is important in considering the principle of intelligence.

Meanwhile, even though there is no direct relation with hardware, the discussion of items that cannot be explained engineeringly, such as “consciousness”, “will”, “concept”, etc. will be closer to psychology and “literature on my own mental scenery”. But it seems be able to handle them in the research field of artificial intelligence in the future.

With context generation ability, we keep community by speaking and writing many sentences. In addition, we will study the underlying context structure from natural phenomena and make it subject to research. The context structure inherent in natural phenomenon was given by “Creator”? No, it is inevitable that thinking with a context structure occurs because the recognition act itself starts with the activation of neurons that accept subsequences presented in this article. In other words, our framework of thought with a context structure is derived from the neural structure of our brain, so our thinking cannot cross that frame. I want to think so.

How the neural network presented in this paper will elucidate the intellectual behavior of animals including language, I want to solve the missing links one by one even though it is far from Bach which Dennet aims.

Acknowledgements

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