NATURAL AND ARTIFICIAL INFORMATION PROCESSING SYSTEMS:

A Preliminary Observation toward a Model of the Brain

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1. Introduction

As living bodies are complex systems, understanding their functions and structures is naturally very difficult. But to explore the complexity of living bodies, the well defined terms of artificial systems or models are often used analogically.

One example of this is "feedback," a term from automatic control systems. This has been often discussed by N. Wiener[18] and others, and many attempts have been made to explain the phenomenon of homeostasis in living organisms in terms of automatic control systems.

Another example is von Neumann's self-reproducing automaton.[10] This automaton, since it is itself well defined, supplies well defined notions to the theory of self-reproduction of living bodies. Although the automaton is quite different from actual living bodies in points other than self-reproduction, it makes clear the function and the necessity of the gene, i. e., to serve as the tape on which the structure of the self-reproducing automaton is described. The above mentioned two examples seem to show the significance of taking an analogy between natural and artificial systems.

The most complex artificial information processing systems are computer systems in spite of the fact that they are far less complex than brains. The comparison between them at the level of constituent elements, i. e., the neurons and the logical elements of computer systems, has been discussed by many authors. In this paper, comparison will be concerned with systematic, macroscopic or functional aspects.

It has been often said that one of the main differences between brain systems and computer systems is that the former process information in a parallel mode while the latter do so sequentially. But recent computer systems adopt multiprocessing (or multiprogramming) which consists of parallel processes, and now the comparison seems to be closer.

2. Established Experimental Phenomena of Brains

The most advanced mental functions of brains are said to be due to the neocortex. The neocortex has a two dimensional structure like a carpet.[11] According to Lorente de Nó, a neocortex consists of columnar or cylindrical elementary units in which all kinds of constituent elements of the cortex (i. e., neurons) appear,[2] making up a single layer which may be called a cortical "carpet." Anatomically, the carpet of the neocortex is closely connected to the thalamus in the brain stem. One columnar elementary unit of the neocortex corresponds to one ('specific') afferent thalamocortical fiber, i. e., one elementary unit is reached by one axon which originates from a neuron in the thalamus. Also Mountcastle confirmed by physiological measurements the prediction of Lorente de Nó that the columnar arrangement of afferent fibers and cortical neurons has functional meaning.[8] The thalamocortical relation may be shown schematically as in Fig. 1.

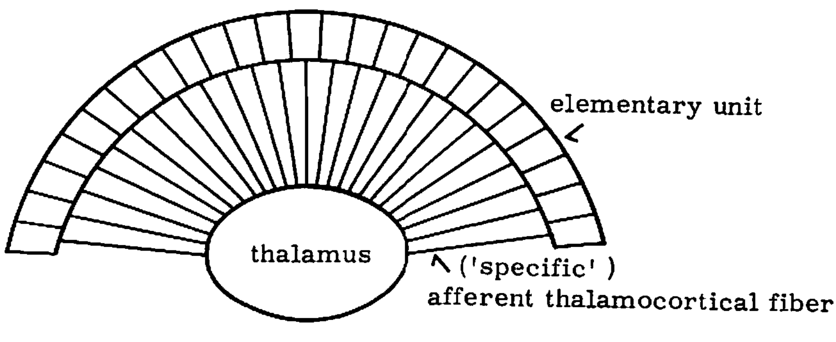

Fig. 1 - A schematic diagram of thalamocortical relation.

(Efferent corticothalamic fibers are not shown in this diagram.)

According to Pavlov, the states of the cortex can be divided into two categories, excitatory and inhibitory.[4] Electroencephalograms show that there are two types of brain waves, representing the alpha rhythm and the beta rhythm. In the active mental state of a human, a large part of his neocortex shows the beta rhythm, while in the inactive (calm) mental state, most of his neocortex shows the alpha rhythm. By electrical measurements, it has been shown that those parts of the cortex showing the beta rhythm are electrically more active than those showing the alpha rhythm.[1] Beta rhythms are of more than 20 Hz, of smaller amplitude and irregular, while alpha rhythms are of about 10 Hz, of larger amplitude and regular. We can consider that that part of a cortex which shows the alpha rhythm is in an inhibitory state while that part of a cortex which shows the beta rhythm is in an excitatory state.

The well established phenomenon of the augmenting response (AR) is such that the electrical stimulation of a part of the thalamus at 8-12 Hz causes the corresponding part of the neocortex to show an alpha-rhythm-like state while the stimulation at more than 16 Hz causes it to show a beta-rhythm-like state.[6] This leads us to an assumption that the state (excitatory vs. inhibitory) of the neocortex is somehow influenced by the thalamus.

3. A Model of the Brain and the Multiprocessing Computer System

Localization of brain functions is proved by the behavior of patients who have had particular parts of their cortices injured. For example, astereognosis or tactile agnosia is related to injury in the association area near the somatosensory area.[15] As for sensory areas, evoked potentials by sensory stimulations also locate the corresponding particular areas.

In spite of the above, advanced mental activity is not merely a collection of mutually independently functioning processes of the neocortex but a close integration of them. According to Penfield, it is clear that the brain system must have some kind of harmonization or integration mechanism in its central part which must be a function of the brainstem.[11] We here hypothesize further, as discussed above, that the integration of the neocortex is accomplished by the thalamus. This paper intends to show that it might facilitate understanding the functioning of the system if we could assume that the functions of the thalamus and the cortical elementary units were interpreted in terms of some special analogous notions in modern multiprocessing (or multiprogramming) computer systems.

In the present day computer system which embodies multiprocessing (or multiprogramming) , information is processed in a parallel fashion by each 'process.'[13, 14, 19, etc.] The whole system contains many identical processes, but it has also a so-called traffic controller or basic supervisor. From here down, let us compare the elementary units of the neocortex to the processes in a multiprocessing system and the thalamus to the supervisor (traffic controller).

The supervisor supervises the activity of all processes, and also intercepts incoming external signals. Processes mutually cooperate and in a sense communicate with one another, but in this interprocess communication signals transmitted via the supervisor (which determines the state of each process) are most important and indispensable.

According to Penfield, then, the most important signals of intracortical communication go through the thalamus whereas the signals that pass through the association fibers which connect cortical points directly are less important.[11]

The main objective of the supervisor is to keep the whole system safe. Each process has flexibility or versatility to execute various programs and occasional errors are inevitable in such a complex system. In order that an error in one part of the system does not result in an overall malfunction of the whole system, separation of the supervisor as a more reliable subsystem is necessary, and this supervisor prevents each process from interfering with its own operation or with another process. Therefore, the supervisor itself should not be versatile but should instead be special or restricted in its functions. In fact, exactly by this reason, various functions of the supervisor have been gradually transferred to individual processes and the supervisor itself is becoming smaller and simpler in more recent large multiprocessing systems.

In the case of brain systems, injury to a part of the neocortex can be compensated by other parts of the neocortex but injury to the thalamus cannot be, and consequently the latter often brings about permanent unconsciousness.[11] A rule of evolution of brains, i. e., encephalization or corticalization, holds that the more advanced an animal is, the more are functions transferred from its subcortex to its cortex.[7] Advanced animals learn many things a posteriori and a posteriori acquisition is due to the neocortex, because this system must be flexible and changeable, which however inherently introduces susceptibility to errors.

As for incoming external signals, it is well known that external sensory signals change the brain waves of the relevant part of the neocortex from the alpha rhythm to the beta rhythm ('alpha-blocking'). Thus auditory signals change the state of the auditory area; somatosensory signals excite the pertinent part of the somatosensory area, etc. Also, sensory signals are known to go into the neocortex only via the thalamus.

In multiprocessing computer systems, the state of each process is divided into two categories, 'waked-up' and 'blocked.' Waked-up processes are in an activated state while blocked processes are in an inactive state and the latter process no information. Processes are blocked until some external input signal arrives. When an external input signal comes to the supervisor (traffic controller), the supervisor wakes up the pertinent process, and the latter, in turn, via the supervisor, wakes up various other relevant processes. The state (waked-up vs. blocked) of each process is determined by its supervisor (traffic controller) and not directly by other processes. Processes can control other processes only through the supervisor. They in this way jointly process the input information.

Then, in analogy to this artificial system, we may speculate on the biological system as follows. Upon receipt of an input signal, the pertinent elementary units are selected and excited by the thalamus, and the activity of these units begins, and as the result they send signals to the thalamus. The thalamus processes the signals and decides which elementary units to excite next. The excited units, then, send computed signals to the thalamus in return, and so forth. This might explain the several hundred-millisecond latency of alpha-blocking.

It should be noted that the above mentioned concepts in computer science are intuitively but clearly understood by the specialists, and it has been demonstrated that these are useful in enabling them to better handle the complexities of modern artificial information processing systems. Some concepts analogous to them may well be useful also in coping with the complexities of natural information processing systems.

Pavlov tried to explain brain functions as variations in a mosaic pattern consisting of excited vs. inhibited pieces. According to him, each point of the neocortex switches its state between the excited and the inhibited as time passes.[4] If this "point" of the neocortex is interpreted as one elementary unit, our model seems quite similar to Pavlov's. In our model, in addition, the role of the thalamus is also defined.

Given this basic framework, what we should do next is to find out the "programs" of each elementary units and the thalamus. We are not yet in the position to discuss this problem in general.

4. The Thalamocortical Coding

In this connection, however, we might pay attention specifically to the intrinsic rhythm of brains. Many suggestions have been made concerning the clock or pacemaking mechanism of the central nervous system.[17, 18, etc.] But, Walter reports that the more carefully the fine structure of the alpha rhythm is studied, the less do these phenomena seem to implicate a central pacemaker.[16] In spite of that, we might be able to consider local (not central) pacemaking mechanisms. Periodicities (20-30 Hz) in impulse sequences of ventrobasal thalamic neurons have been observed.[9, 12] The existence of highly regulated impulse sequences has been reported.[12] No discussions or experimental reports seem to have appeared which are concerned with the relation between the periodicity and the intrinsic rhythm of brains. If it is true that the neuronal activity of various parts of the thalamus has a periodicity of either the 10 Hz alpha-rhythm frequency or about twice that, then we can speculate about thalamo-cortical coding as follows. In interpreting the augmenting responses (i. e., the fact that an electrical stimulation of the thalamus at about 10 Hz causes an alpha-rhythm-like wave, while stimulation at about 20 Hz causes a beta-rhythm-like wave), let us hypothesize that a ('specific') thalamocortical fiber carries timing impulses of 10 Hz (for local synchronization). If no impulse exists between the two adjacent timing impulses, the pertinent elementary unit acquires the inhibitory state, while, if an impulse exists between the two adjacent timing impulses, the unit takes the excitatory state (Fig. 2). If inhibitory elementary units are dominant in some area of a neocortex, it will show the alpha rhythm, whereas, if excitatory units are dominant, it will show the beta rhythm. This remains at present only a suggestion.

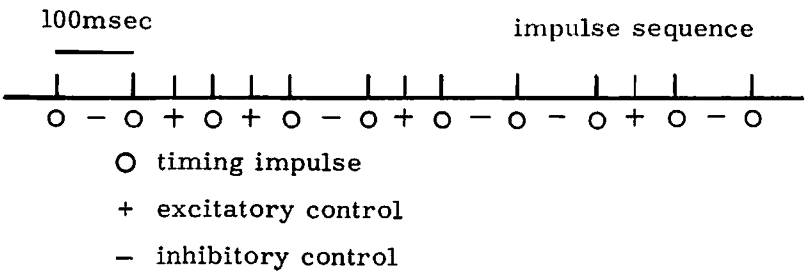

Fig. 2 - A hypothetical thalamocortical coding.

Although this paper does not touch on the functions of the reticular formation,[5] it must be deeply related to the thalamocortical relation.[3] It might be concerned with the regulating function of the whole nervous system, especially as a synchronization or timing mechanism.

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References

1) Caspers, H. and H. Schulze: "Die Veränderungen der corticalen Gleichspannung während der natürlichen Schlaf-Wach-Perioden beim freibeweglichen Tier," Pflügers Arch. ges. Physiol. 270, 103-120 (1959), etc.

2) Fulton, J. F. : The Physiology of the Nervous System, 3rd ed., New York and London: Oxford Univ. Press, 1949.

3) Jasper, H. : "Diffuse Projection Systems: The Integrative Action of the Thalamic Reticular System," EEG Clin. Neurophysiol. 1, 405-420, etc. (1949)

4) Kogan, A. B. : Osnovy Fiziologii Vysshej Nervnoj Djejatjelnostji, Moscow: Gosudarstv. Izd. [Vysshaya Shkola], 1959, etc.

5) Magoun, H. W. : The Waking Brain, 2nd ed., Springfield, Illinois: Charles C. Thomas, Publisher, 1963, etc.

6) Morrison, R. S. and E. W. Dempsy: "A Study of Thalamocortical Relations," Amer. J. Physiol. 135, 281-292 (1942), etc.

7) Motokawa, K. : Dainoo-Seirigaku (Physiology of Cerebrum), Tokyo: Nakayama Shoten, Ltd., 1964, etc.

8) Mountcastle, V. B. : "Modality and Topographic Properties of Single Neurons of Cat's Somatic Sensory Cortex," J. Neurophysiol. 20, 408-434 (1957).

9) Nakahama, H., S. Hishioka, T. Otsuka, and S. Aikawa: "Statistical Dependency between Interspike Intervals of Spontaneous Activity in Thalamic Lemniscal Neurons," J. Neurophysiol. 29, 921-934 (1966).

10) von Neumann, J. : Theory of Self-Reproducing Automata, Urbana and London: University of Illinois Press, 1966.

11) Penfield, W. and L. Roberts: Speech and Brain Mechanism, New Jersey: Princeton University Press, 1959.

12) Poggio, E. G. and L. J. Viernstein: "Time Series Analysis of Impulse Sequences of Thalamic Somatic Sensory Neurons," J. Neurophysiol. 27, 514-545 (1964).

13) Saltzer, J. H. : "Traffic Control in a Multiplexed Computer System," MAC-TR-30 (Thesis), M.I.T., Cambridge, Mass. (1966).

14) Thomson, R. N. and J. A. Wilkinson: "The D825 Automatic Operating and Scheduling Program," Proc. AFIPS 1963 Spring Joint Computer Conf. 23, 41-49, New York: Spartan Books, 1963.

15) Tokizane, T., ed.: Noo-no Seirigaku (Physiology of Brain), Tokyo: Asakura Shoten, Ltd., 1966.

16) Walter, W. G.: "Spontaneous Oscillatory Systems and Alterations in Stability," Chapter 7. I. in Progress in Neurobiology: V. Neural Physiopathology, Grenell, R. G. ed. New York: Harper and Row, Publishers, 222-257, 1962.

17) Walter, W. G.: The Living Brain, London: Gerald Duckworth and Co., Ltd., 1953.

18) Wiener, N.: Cybernetics, 2nd ed., New York: John Wiley and Sons, Inc., 1961.

19) Witt, B. I.: "The Functional Structure of OS/360 Part II Job and Task Management," IBM Systems J. 5, 12-29 (1966).