Dynamics of “Neuron Ring”

Computer Simulation of Central Nervous System of Starfish

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Summary. Dynamics of “neuron ring” has been studied by means of computer simulation. The ring is formed of some number of identical neurons which loop together with lateral inhibitions and are stimulated by a command neuron. In this model, we assumed that each neuron has individual activity intrinsically without any inputs. The function of each neuron is essentially the same as that of Reiss’ model; each neuron receives one excitatory and two inhibitory signals and when the membrane potential exceeds the instantaneous threshold level rises up for a period. This report is the first step towards the problem described above. We have taken the behavior of starfish as a typical example to be studied. A starfish seems to be completely “symmetrical” as far as motor organs are concerned. When it walks, any arm can be a leading arm by which the direction of walking is determined. A starfish shows another and more interesting characteristic. When it is placed upside down, it turns itself over by coordinating the motions of the five arms. It should be noted that coordination is preceded by individual random motion of each arm. While each arm is making separate motions, the leading arm for coordination is selected from the five arms, and thereafter the individual random motions are inhibited and a systematic turn-over motion starts.

The animal system has a high degree of ability to coordinate a multiple number of subsystems and to fit behavior into one unified system. Each subsystem, naturally, has its own respective specific function. If there is no supervisory control, each works autonomously and independently from the others. However, when these subsystems are brought together and unified into one large system, their independent, random actions are suppressed. Autonomous activities of subsystems are organized into one ordered behavior of corrective motion. What mechanism controls this organizing process? Modern engineering has no technique by which it can perform such feats of integration. So it is very interesting not only for physiologists but also for system engineers, to find out the secrets of the supervisory control mechanism observed in the animal system.

This report is the first step towards the problem described above. We have taken the behavior of starfish as a typical example to be studied. A starfish seems to be completely “symmetrical” as far as motor organs are concerned. When it walks, any arm can be a leading arm by which the direction of walking is determined. A starfish shows another and more interesting characteristic. When it is placed upside down, it turns itself over by coordinating the motions of the five arms. Fig. 1 shows the turn-over motion of a starfish. It should be noted that coordination is preceded by individual random motion of each arm. While each arm is making separate motions, the leading arm for coordination is selected from the five arms, and thereafter the individual random motions are inhibited and a systematic turn-over motion starts.

A starfish has a circular nervous connection around its mouth which is presumed to be the central nervous system determining coordination on the five arms. Fig. 2 is a schematic diagram of the central nervous system drawn by Smith (1965). We consider the central nervous system of the starfish to be a good example for research in our problem, as described
above. From neurophysiological study, we have derived a very simplified model of it and named it the “neuron ring”. As shown in Fig. 3, the ring is formed of a number of identical neurons which loop together with lateral inhibitions and are stimulated simultaneously by a command neuron. We shall now discuss some results of our computer simulation study on the dynamics of this “neuron ring”.

We have conceived a system with these characteristics:

(1) the system is completely “symmetrical”; that is, each neuron has exactly the same properties as any other and, in a circle, has mutual interaction between its neighboring two neurons, (see Fig. 3) and

(2) each neuron has individual activity intrinsically without any inputs.

Our aim is to discover the mechanism through which the individual activities of neurons make a transition into ordered behavior when they are stimulated externally.

2. The Model and Computer Simulation

Fig. 3 is a schematic diagram of the “neuron ring”. Suppose the system to be composed of \( n \) motor neurons and one command neuron. Each motor neuron has three input terminals, one of which receives excitatory signals from the command neuron and the other two receive inhibitory signals from the neighboring motor neurons. We assume that the motor neuron fires and sends out an inhibitory signal to the two neighboring neurons when the membrane potential exceeds the instantaneous value of threshold. The membrane potential may be the temporal and spatial summation of three inputs, and the threshold value is supposed to be a function of the history of the neuron excitation state described as follows.