How Single Neuron Processes Information

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Abstract

This paper proposes the hypothesis of how a single neuron processes information, that is, a specific Frame of Stimuli can only produce a specific Frame of Responses, or multi-value operation, that is, a specific combination of multiple input values generates a specific combination of multiple output values, and then discusses the possibility of such hypothesis.

Keywords

Stimulus, Responses, Receipt End, Output End, Frame, Processing

1. Introduction

1.1 Purpose

The purpose of this paper is to propose a hypothesis about how a single neuron processes information. Understanding how a single neuron works can explain how all biological neural systems work, because all biological neural systems are composed of single neurons that are connected together in some way, and the main differences among all neural systems are the routing of neural network and the quantities and varieties of neurons. Therefore, understanding the working mechanism of a single neuron is the basis for understanding the working mechanism of all neural systems and even our human brain, and it is needless to overstate its importance.

1.2 Shared characteristics of single neurons

From the existing experiments and research in the field of neuroscience, it is known that the neural system consists of multiple neurons. Although there are many types of neural cells and various morphologies, they all have some basic common characteristics:

a. Every neuron has dendrites and axons, and the connections between dendrites and axons are synapses. The ends of dendrites and axons have multiple branches that establish synaptic connections with other cells at multiple positions.

b. Neurons receive external information (Stimuli) through their dendrites and output processed results (Responses) through their axons. Every neural cell has dendrites as Receipt End and axons as Output End.

c. Neurons release neurotransmitters in the form of vesicles in the synaptic cleft through axonal terminals, and receive neurotransmitters released by axonal terminals of other neurons in the synaptic cleft through receptors on dendritic terminals.

The above characteristics are mainly applicable for interneurons, excluding sensory neurons and motor neurons, because the Receipt End and Output End of the two are different. The Receipt End of sensory neurons receives Stimuli directly from the outside environment, and the Output End of motor neurons directly commands effectors to perform actions.[1]

1.3 Basic task of a single neuron

Although there are different kinds of neurons, the basic task performed by each or all neurons is the same, that is, receiving information, processing information, outputting results, and performing the "Receive-Processing-Output" process. For "Receive" and "Output", the known facts are relatively clear, but the "Processing" is still in a completely unknown state, so this paper proposes a hypothesis for this "Processing".

2. Definition of keywords

For clarity, definitions of the main keywords used in the hypothesis are given below:

Stimuli: For sensory neurons, Stimuli refer to signals received from the outside environment, such as light, sound, heat, etc.; For interneurons, Stimuli refer to the neurotransmitters received by the dendritic terminals in the synaptic cleft that are released from the axon terminals of other neurons.

Responses: For motor neurons, Responses refer to the release of substances from the neuron to the effectors through the axonal terminals; For interneurons, Responses refer to the release of substances by the neuron through the axonal terminals in the synaptic cleft to the dendritic terminals of other neurons. At the same time, Responses also includes the morphological changes of neurons and the establishment of synaptic connections with other neurons. But for these Responses, because they are less relevant to the topic of this paper, they are omitted and not discussed.

Receipt End: It refers to the postsynaptic portion on all dendritic terminals of a neuron, but this is not applicable to sensory neurons.

Output End: It refers to the presynaptic portion on all axonal terminals of a neuron, but this is not applicable to motor neurons.

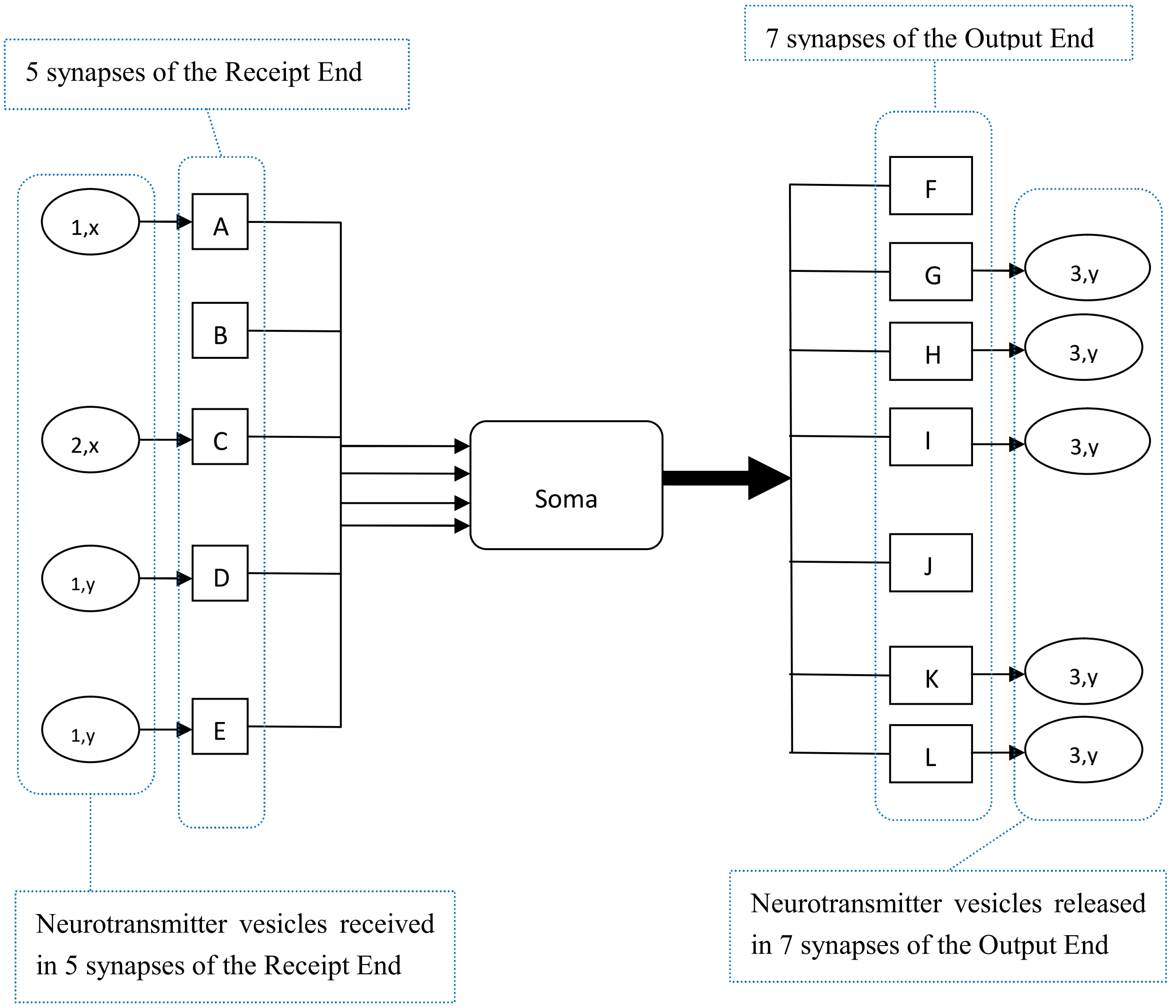
Frame: It refers to a whole combination of all Stimuli received by all Receipt Ends of a neuron or a group of associated neurons at one moment; It also refers to a whole combination of all Responses produced by all Output Ends of a neuron or a group of associated neurons. For example, if we see an image, we can consider this image as a Frame of Stimuli.

Processing: It refers to a specific process that a single neuron undergoes between receiving Stimuli at the Receipt End and producing Responses at the Output End.

3. Hypothesis about how a single neuron processes information

Hypothesis details: At one moment, a neuron receives a specific Frame of Stimuli at its Receipt End, and a specific Frame of Responses is produced at the Output End of the same neuron after a short period of time (the specific duration is unknown) through some unknown processing inside the entire neuron cell. That is to say, there is a certain rule inside the neuron cell, for a specific Frame of Stimuli received, only one specific Frame of Responses is produced, ensuring that the Frame of Stimuli only one-to-one corresponds to the Frame of Responses. This one-to-one correspondence between Stimuli and Responses is illustrated below with a hypothetical example.

Suppose a neuron has 5 synapses at the Receipt End and 7 synapses at the Output End. The 5 synapses at the Receipt End of the neuron can be coded as A, B, C, D, and E, respectively; The 7 synapses at the Output End of the neuron can be coded as F, G, H, I, J, K, and L, respectively; The types of neurotransmitters that this neuron can release and receive in all of the above 12 synapses coded as x and y; that is, 2 types of neurotransmitters; The quantities of vesicles that can be received and released at the Receipt End and Output End are coded as 1, 2 and 3; that is, three quantities of vesicles (1, 2 or 3 vesicles are received or released at a time). When the 5 synapses at the Receipt End receive a Frame of Stimuli at one moment; for example, one vesicle containing neurotransmitter x is received in synapse A, the stimulus is coded as [A:1,x] (where A stands for the synapse, 1 stands for one vesicle, x stands for neurotransmitter type, ":" and "," act as spacers and do not represent any meaning); two vesicles containing neurotransmitter x are received in synapse C, which is coded as [C:2,x]; one vesicle containing neurotransmitter y is received in synapse D, which is coded as [D:1,y]; one vesicle containing neurotransmitter y is received in synapse E, which is coded as [E:1,y]. Then the entire Frame of Stimuli received in these 5 synapses at the Receipt End of the neuron at this moment is [A:1,x/B:0,0/C:2,x/D:1,y/E:1 ,y]. This Frame of Stimuli will be processed by that neuron and specific neurotransmitters will be released in specific synapses at Output End, producing a specific Frame of Responses. Suppose after receiving the Frame of Stimuli [A:1,x/B:0,0/C:2,x/D:1,y/E:1,y], the neuron releases three vesicles containing neurotransmitter y in synapse G of the Output End, which is coded as [G:3,y]; it releases three vesicles containing neurotransmitter y in synapse H, which is coded as [H:3,y]; it releases three vesicles containing neurotransmitter y in synapse I, which is coded as [I:3,y]; it releases three vesicles containing neurotransmitter y in synapse K, which is coded as [K:3,y], it releases three vesicles containing neurotransmitter y in synapse L, which is coded as [L:3,y]; then the entire Frame of Responses is [F:0,0/G:3, y/H:3,y/I:3,y/J:0,0/K:3,y/L:3,y], as shown in Figure 1 below. In this way, neurons are able to output specific Frame of Responses for specific Frame of Stimuli, achieving the specificity that one Frame of Stimuli corresponds to only one Frame of Responses.



The above figure can be simplified as the following:

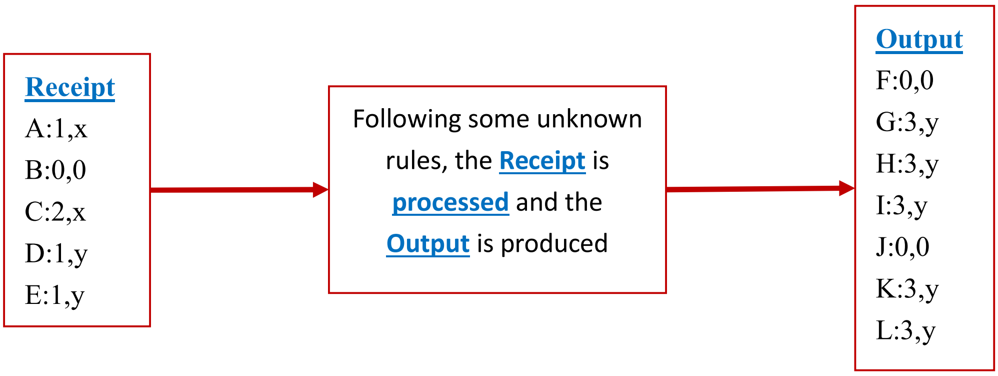


Figure 1:One-to-one correspondence between Frame of Stimuli and Frame of Responses

If the above neurons are connected in parallel and in series with other same type of neurons to form a group of associated neurons, the whole group of associated neurons can also output a larger specific Frame of Responses for a larger specific Frame of Stimuli received at one moment, as said in above example. However, such a neural network that is composed of the above said neurons can only output a specific Frame of Responses for a specific Frame of Stimuli received at one moment, but cannot output a specific sequence of Frames of Responses for a sequence composed of multiple Frames of Stimuli received at multiple consecutive moments.

Then further suppose that there is another type of neuron (Neuron Type II) that does not output any Frame of Responses when receiving one Frame of Stimuli at one moment, but outputs one Frame of Responses after receiving another Frame of Stimuli at a later moment, or output one Frame of Responses after receiving three or more consecutive Frames of Stimuli. If Neurons Type II are connected in parallel with the neurons that output one Frame of Responses after receiving one Frame of Stimuli (Neuron Type I), the specificity of outputting one specific sequence of Frames of Responses for one specific sequence of Frames of Stimuli can be achieved; namely, one specific sequence of Frames of Responses can be output for one specific sequence of Frames of Stimuli received consecutively during a period of time. The Neurons Type II either directly acts on the axon of Neurons Type I to change its Frame of Responses, or its Responses can be joined with the Frame of Responses output by Neurons Type I to produce a new Frame of Responses. As shown in the Figure 2 below, the red, blue and green graphics represent three neurons respectively; T1, T2 and T3 are three consecutive moments; The black numbers and letters represent the neurotransmitter codes released and received by neurons in the synaptic cleft, and the black squares represent no neurotransmitter released. Among them, the red and blue neurons are Neurons Type I, that is, they will only output one Frame of Responses after receiving one Frame of Stimuli at one moment, and the green neurons are Neurons Type II, that is, only output one Frame of Responses after receiving two or more consecutive Frames of Stimuli.

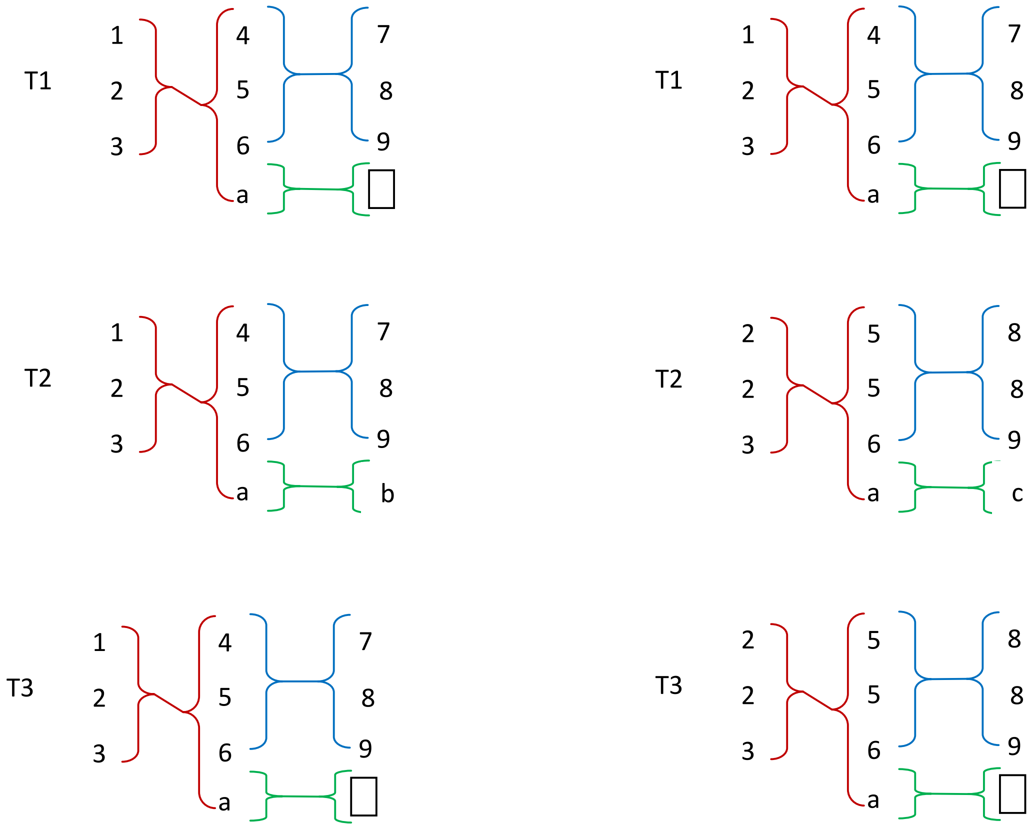


Figure 2: One specific sequence of Frames of Stimuli

The Figure 2 above is a group of associated neurons consisting of two types of neurons. The group of associated neurons can produce a specific sequence of Frames of Responses for a sequence of three Frames of Stimuli. Through more complex parallel and serial connections of these two types of neurons, the resulting neural network can output a corresponding sequence of Frame of Responses for a larger and longer sequence of Frame of Stimuli.

4. Discussion of the Possibilities of the Mechanisms Above

4.1 What is life? And what does a single cell do?

Life is an assemblage of substances that can exchange substances with the external environment to execute a huge specific sequence of chemical reactions. Or a more straightforward explanation is that life is just a sequence of chemical reactions. If this sequence of chemical reactions is interrupted, life ends, which we call death. The cell is the basic unit that executes this sequence of chemical reactions. It can be said that the cell is a huge city of molecular machines driven by electromagnetic attraction and repulsion of atoms, executing billions of chemical reactions, and the latter chemical reactions depend on the accomplishment of former chemical reactions. It is more similar to a huge complicated Domino Toppling, or a large bundle of cross-parallel causal chains. The concept about life and cells proposed here is to show that all chemical reactions executed by cells are pre-designed and pre-arranged, and that all reactions are executed in an orderly manner accurately, without any tolerance for error. So neurons are also cells, but neurons have evolved special receipt and output systems for transmitting and processing information. One Frame of Stimuli is received at the Receipt End, and then a specific Frame of Responses is produced at the Output End, and there must be some kind of processing in between, and this processing must follow certain rules. Although these rules are not known, it is certain that neurons must have such rules, and the same rules must apply to all neurons. Thus, when a neuron receives a Frame of Stimuli at the Receipt End, the neuron will follow some rules and produce a Frame of Responses at the Output End. And when the neuron receives the exactly same Frame of Stimuli again, it shall also produce the same Frame of Responses because it follows the same rules. For example, every time a needle pricks our skin, we feel pain, without exception. Every time we see an image, we can describe exactly what we saw, such as seeing the letter A, and we can draw a similar figure, even if we don't know what the A means. Examples of such one-to-one correspondence between Stimuli and Responses are numerous and will not be repeated here.

4.2 How does the correspondence between Stimuli and Responses come into being?

For multicellular organisms, if one of their cells can sense the external environment, and then tell other cells to perform certain actions according to the sensed situation, such as commanding muscle cells to contract, such cells must be very advantageous to the organisms. So it can be imagined that in the early stage of evolution of life, that is, just when the single-celled organisms evolved into multicellular organisms, the cells began to differentiate, and one or some cells began to differentiate and evolve into the original neurons. Its function is to sense the external situation and command other cells to respond appropriately. For example, it senses heat and then commands other cells to move away from the heat source. Of course, the original neurons responded to external situations in miscellaneous ways, such as sensing heat, commanding other cells to approach the heat source, or perform other actions. But only organisms that respond appropriately will survive, and the mechanisms by which neurons respond to specific Stimuli will be passed on to offspring through inheritance and reproduction. Then if the organisms were to sense larger and more complex Stimuli, it would need more of such neurons. So after a long period of evolution, the neural system has evolved from a single neuron to a neural network with hundreds of billions of neurons. That is, with the lapse of time, neurons were accumulated one by one, and gradually evolved into today's complex neural system. Therefore, it can be seen that the higher the complexity of the neural network, the higher the complexity of the Stimuli that it can receive, and the higher the complexity of the Responses that it can output, and these three are completely positively correlated. Now, the above hypothesis of the correspondence between the Stimuli and Responses of a single neuron can perfectly explain the evolution process of the neural system, that is, the process of neurons accumulating one by one over time. It can also explain why for a specific stimulus, organisms only have one particular response, not any other responses.

4.3 How the above mechanism of neuron processing information be achieved?

After the neuron receives Stimuli at Receipt End, it executes some internal processing in the neural cell and produces Responses at Output End. So neurons require certain systems within the neural cell to execute this process. Neural cells must have a system that can connect the Receipt End to Output End and be able to perform certain actions in an orderly manner, such as the transportation of substances. Then, there is indeed such a system inside the cell, which is the cytoskeleton, including microtubules, microfilaments and intermediate fibers. If a cell is likened to a city of molecular machines, the cytoskeleton is the crisscrossing roads in the city. All chemical reactions executed orderly inside the cell depend on the cytoskeleton. There is a complex cytoskeletal network between the Receipt End and Output End of neurons, and this network is sufficient to achieve a one-to-one correspondence between Stimuli and Responses. Of course, the participation of other organelles is required to complete the whole process, but how is unknown. We don't yet know the sequence of chemical reactions executed by a single cell, that is, all the chemical reactions a cell executed at one moment, then all the chemical reactions executed at the next moment, and so on. Although the specifics are unknown, the neural cell has the competence to achieve a one-to-one correspondence between Stimuli and Responses.[2]

4.4 Multi-valued operations by single neuron?

It can be imagined that for multicellular organisms, if a neuron can sense the external situation from multiple positions, and then send the commands to multiple cells, as compared with a neuron that can only sense the external situation from one position, and then send the command to only one cell, the former is obviously more efficient than the latter, which would explain why both dendrites and axons have branches. As mentioned in the above example, if we consider the [A:1,x/B:0,0/C:2,x/D:1,y/E:1,y] as a value at Receipt End, the branches at Receipt End and Output End can increase the quantity of different values for Frames of Stimuli and Responses. Although the operation rule for specific Stimulus to produce specific Response is unknown, as long as multi-valued input can produce multi-valued output, we can consider the processing of neuron to be a very powerful multi-valued operation. A single neuron can receive and produce a great number of input and output values of different combinations, as compared to the transistors in CPU that only have two input values and two output values (high and low levels, ON and OFF). In addition to branches that can generate multiple different values, the types of neurotransmitters and the quantities of vesicles can further increase the number of different values. So from an angle of operation, it is critical to create as many operational values as possible. So neurons have many branches, a great number of synapses, dozens types of neurotransmitters and other neuronal substances, several types of vesicles and different mixtures in a single vesicle, all of these factors contribute to increase the number of operational values.

5. Conclusion

Although the above hypotheses and discussions are pure speculation, there is no determinant evidence to prove it. But the good side is that there is no solid evidence to falsify it. Moreover, the above hypothesis can be used to explain all neurological phenomena from primitive organisms with just a thousand of neurons to intelligent creature with 100 billion neurons, and the hypothesis also conforms to the evolutionary framework of the neural system.

CRediT authorship contribution statement

Huan Liang wrote the original draft and final version of above paper.

Declaration of Competing Interest

The author did not have any conflict of interest.

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