Volume-2, Issue-8, December-2018: 237-240
International Journal of Recent Innovations in Academic Research ISSN: 2635-3040

Modeling Human Neural Network

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Abstract: The objective of this research study was modeling human neural network using mathematics concepts. A survey design approach was used. Purposive sampling approach was used. Formal Neuron and Perception are common models of human neural network. The Logical Functions such as NOT, and AND can also model the human neural network.
Keywords: Biological neural network, Motor, Sensory and Associative neurons.

Citation: Kassahun Tesfaye Agzew. 2018. Modeling Human Neural Network. International Journal of Recent Innovations in Academic Research, 2(8): 237-240.

Introduction

This research paper was about the modeling of the human neural network using mathematics concepts. The interest to study human neural network is their remarkable ability to derive meaning from complicated data, can be used to extract patterns and detect trends that are too complex to be noticed by either humans or other computer techniques.

Statement of the problem

Human neural network is network of biological neurons. Basically the biological neurons include sensory, motor and associative neurons. Each neuron receives inputs and provides outputs.

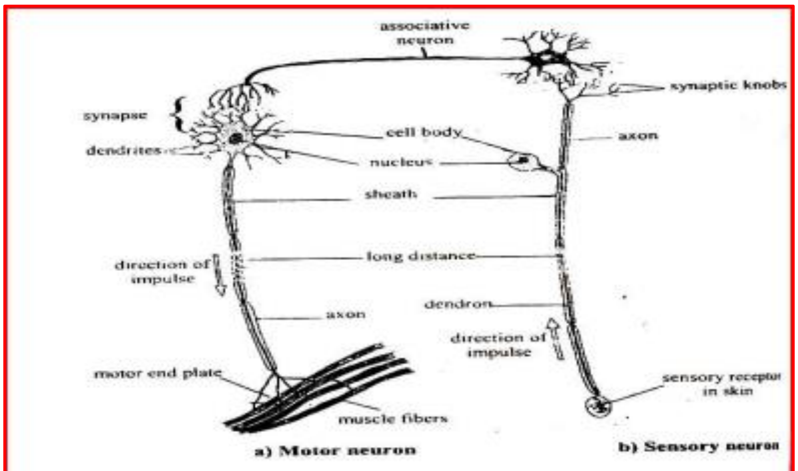

Fig. 3.3 The connections of a sensory, a motor and an association neuron

Figure 1. The structure of Sensory, Motor and Associative Neurons

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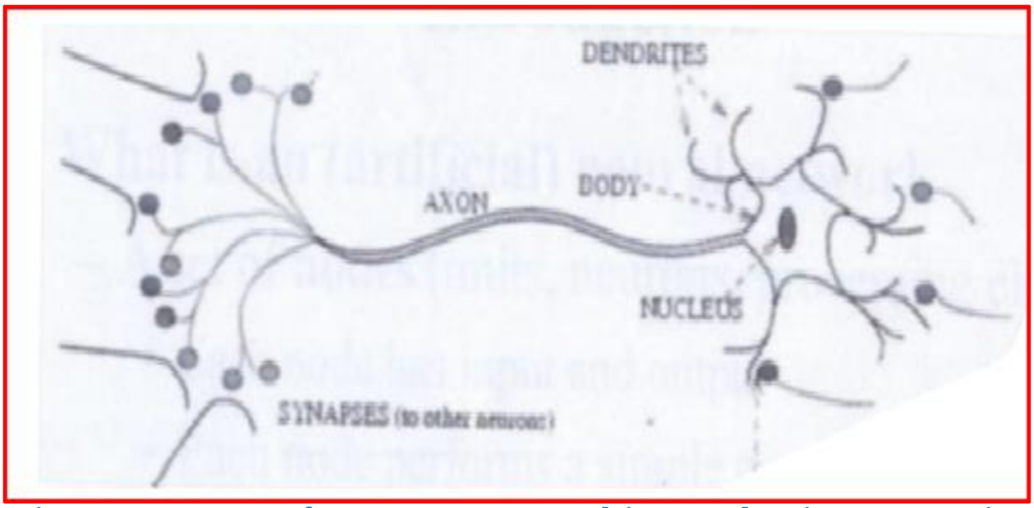

Figure 2. Structure of Axon, Synapse, Dendrites, Nucleus in Human Being

Each neuron structurally has a cell body, an axon, and many dendrites. Can be in one of the two states: firing or rest. Neuron fires if the total incoming stimulus exceeds the threshold. If the total incoming stimulus is less than the threshold, then the neuron will be at rest. Threshold is the smallest detectable sensation. Synapse is a microscopic gap between axon of one and dendrites of another. In the synapse the neurons exchange information.

The cell body has a large nucleus embedded in dense granular cytoplasm and is variable in shape. A number of short cytoplasmic strands called dendrons arise from the cell body and branch at the end in to thread like extensions called dendrites. Dendrites are parts of the neuron that receive messages from nearby neurons. The axon is a long cytoplasmic fiber which extends from the cell body and ends in terminal branches as can be seen in the above figure.

Formal Neuron

Since the structure of human neurons is complex so to have easily manageable neurons, it is necessary to comprehend the essential functional characteristics of a neuron in a very simplified form. These neurons are known as Formal Neurons.

Definition 1

$$\mathbb{R}^{\boldsymbol{n}} = \left\{ x : x = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix},\ n \in \mathbb{N},\ \ x_i \in \mathbb{R},\ \ i = 1,2 \cdots\ n \right\}$$

A Formal Neuron is a data quadruple $(X,\ Y,\ \sigma,\ S)$, where $X \subseteq \mathbb{R}^{\boldsymbol{n}}$ for some positive integer $n, Y \subseteq \mathbb{R}, S$ and σ are mappings, $S: X \to \mathbb{R}$ and $\sigma: \mathbb{R} \to Y$, respectively. We call X the input value set and Y the output value set. The mapping S is called an activation function and σ is called the output map. However, sometimes a formal neuron will be identified with its Transfer function which is the composed input to output map $f = \sigma \circ S: X \to Y$.

From a biological point of view, the input signals can be viewed to stem from receptors of connected neurons. Then the signals are modified at the synapses and condensed in to a single signal at the soma. If the quantity of these signals surpasses a certain threshold θ, then the neuron fires. The simplest way to model such a neuron therefore uses $Y = \{0,\ \ 1\}$ as its output value set. The output is 1 if the neuron fires and 0 otherwise.

Definition 2

A formal neuron is a neuron whose output is 1 if it fires and 0 otherwise.
The affine linear map $S(x) = S(x_1,\ x_2,\ \cdots,\ x_n) = \sum_{i=1}^{n} x_i w_i - \theta$ is an activation function. The weights $w_i \in \mathbb{R}^n$ for $i = 1, 2, \cdots, n$, model the influence of the synapses on the signal $x_i, \theta \in \mathbb{R}$ represents the threshold and $x \in \mathbb{R}^n$.

Definition 3

A formal neuron that transmits the signal 1 if $\sum_{i=1}^{n} x_i w_i \geq \theta$ and 0 otherwise is called perceptron.

Let‘s define a function called the Heaviside function sat as follows:
$Heaviside\ function\ sat$: $\mathbb{R} \to \{0, 1\}$, which is defined by

$Sat(x) = \begin{cases} 1\ if\ \mathbb{Z} \geq 0 \\ 0\ if\ \mathbb{Z} < 0 \end{cases}$, where $\mathbb{Z} = \sum_{i=1}^{n} x_i w_i - \theta$

Since it transmits the signal 1 if $\sum_{i=1}^{n} x_i w_i \geq \theta$ and 0 otherwise, hence it is called a perceptron.

Notice That

- Heaviside Function sat models the human neural network activity.
- Heaviside function sat is an example of formal neuron.

Example 1: Sigmoid function is a function with continuous value set $[0,\ 1]$ and a monotone function, $\sigma: \mathbb{R} \to [0,\ 1]$ with $\lim_{\mathbb{Z}\to-\infty} \sigma(\mathbb{Z}) = 0$ and $\lim_{\mathbb{Z}\to\infty} \sigma(\mathbb{Z}) = 1$.

Notice That the Sigmoid Function models the human neural network.

Example 2: Fermi function: $\sigma(\mathbb{Z}) = \frac{1}{1+e^{-\mathbb{Z}}}$.

Solution

Step 1: $\sigma(\mathbb{Z})$ assumes values in $[0,\ 1]$
Step 2: $\lim_{\mathbb{Z}\to-\infty} \sigma(\mathbb{Z}) = 0$ and $\lim_{\mathbb{Z}\to\infty} \sigma(\mathbb{Z}) = 1$.

Hence, it is a sigmoid function.

Notice That the Fermi Function models the human neural network activity.

Definition 4

Boolean function is a function whose range is in $\{0,\ \ 1\}$.

Example 3: Logical functions such as $, NOT,$ and AND are Boolean functions.
Boolean functions can be modeled by perceptron.

I. Let $f = NOT$. Then $f: \{0,\ \ 1\} \to \{0,\ \ 1\}$. The perceptron modeling f is given by

Table 1. Input signal versus output signal of f

Input signal	Out Put signal
x	$f(x) = negation\ of\ x$
0	1
1	0

Table 2. Signal Exchange at the synapse

Input Signal	Out Put Signal	Action by Neuron
x	$f(x) = negation\ of\ x$	
0	1	The neuron Fires
1	0	The neuron at rest

Tables 1 and 2 are completed by the rule of negation. Then the model of f is given by the perceptron $f(x) = sat(-x + 0.5)$.

Notice that the perceptron $f(x) = sat(-x + 0.5)$ models the human neural network activity.

II. Let $f = AND$. Then $f: \{0,\ 1\}^2 \to \{0,\ 1\}$.

Table 3. Input signal versus output signal of *f*

Input Signal		Out Put Signal
x_1	x_2	$f(x) = x_1 \wedge x_2$
0	0	0
0	1	0
1	0	0
1	1	1

Table 4: Signal Exchange at the synapse of *f*

Input Signal		Out Put Signal	Action by Neuron
x_1	x_2	$f(x) = x_1 \wedge x_2$	
0	0	0	The neuron at rest
0	1	0	The neuron at rest
1	0	0	The neuron at rest
1	1	1	The neuron Fires

Tables 3 and 4 are completed by the rule of conjunction. The Boolean function f can be modeled by the perceptron $f(x) = sat(x_1 + x_2 - 1.5)$.

Notice that the perceptron $f(x) = sat(x_1 + x_2 - 1.5)$ models the human neural network.

Example 4:

a. $f(x) = sat(-x + 0.5)$
b. $g(x) = sat(x_1 + x_2 - 1.5)$ are formal neurons.

References

1. Kassahun Tesfaye. 2011. Recurrent Neural Network, Addis Ababa University, 1-54 p.