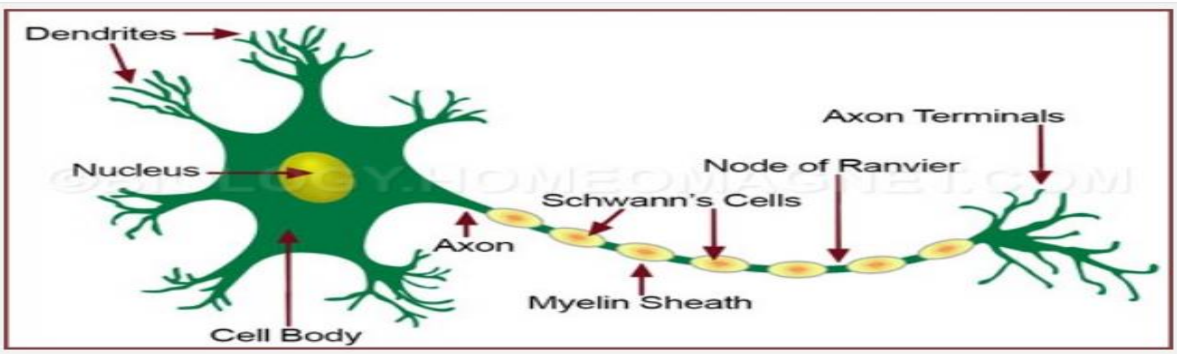
Yog Chaudhary
11727095
ADTA 5550: Deep Learning with Big Data
Professor: Dr. Hamidreza Moradi
University of North Texas **Jan 30, 2024**

PART I: Biological Neural Network & Artificial Neural Network (30 Points)

Question 1.1: Describe (including images for illustration) the human biological neural network and how it works.



Structure of Neuron

Nervous system consists of 2 cells:

- Nerve cells
- Glial cell

The nerve cells are called Neuron, and the glial cells are called neuralgia. Neurons transmit information from one part of the body to another and the glial cells are supporting elements.
Neurons consist of a cell body and two processes:

- Dendron
- Axon

Neurons: Neurons are the basic functional units of the nervous system. They are specialized cells capable of transmitting electrical and chemical signals. Neurons have several key components:

Cell Body (Soma): The cell body contains the nucleus and other organelles. It processes incoming signals from dendrites and initiates outgoing signals through the axon.

Synapse: Point of connection to other neurons

Dendrites: These are branched extensions that receive signals (in the form of neurotransmitters) from other neurons or sensory receptors.

Axon: The axon is a long, slender projection that carries electrical impulses (action potentials) away from the cell body toward other neurons or target cells.

Synapses: Neurons communicate with each other and with muscles or glands through synapses. Point of connection to other neurons

2. Action Potential: When a neuron receives a strong enough signal from its dendrites, it generates an action potential—an electrical impulse that travels along the axon. The action potential is a rapid change in voltage across the cell membrane.

3. Myelin Sheath: Many axons are insulated by a fatty substance called myelin, which acts as an insulator and speeds up the conduction of action potentials. Myelin is produced by specialized cells called oligodendrocytes in the central nervous system and Schwann cells in the peripheral nervous system.

4. Neural Transmission: The action potential travels along the axon in one direction, from the cell body to the axon terminals. This one-way transmission ensures that signals are not disrupted.

5. Synaptic Transmission: When the action potential reaches the axon terminals, it triggers the release of neurotransmitters into the synaptic cleft, the small gap between neurons. These neurotransmitters then bind to receptors on the postsynaptic neuron, either exciting or inhibiting it, depending on the neurotransmitter-receptor interaction.

6. Integration of Signals: The receiving neuron integrates all the signals it receives from various synapses. If the sum of excitatory signals exceeds inhibitory signals, the neuron generates its own action potential.

7. Neural Networks: The brain and spinal cord are organized into complex neural networks where neurons are interconnected in intricate patterns. These networks are responsible for processing sensory information, forming memories, controlling motor functions, and generating thoughts and emotions.

8. Central and Peripheral Nervous Systems (CNS and PNS): The nervous system is divided into the central nervous system (CNS), which includes the brain and spinal cord, and the peripheral nervous system (PNS), which consists of nerves that extend throughout the body.

9. Autonomic Nervous System (ANS): The ANS controls involuntary functions like heart rate, digestion, and breathing. It has two divisions: the sympathetic and parasympathetic systems, which have opposing effects on bodily functions to maintain homeostasis.

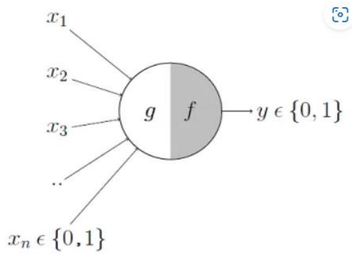
Question 1.2: Describe (including images for illustration) the McCulloch-Pitt neuron model, a.k.a. Threshold Logic Unit, that is considered the simplest neural network and how it works.

The McCulloch Pitts neuron model, created in 1943 by two electrical engineers Warren McCulloch and Walter Pitts, was the first mathematical model to simulate the operation of a biological neuron. Their design is also known as a 'Linear threshold gate.' Their generated model's neurons function under the following conditions:

I. They are binary devices with a 0 or 1 output (Vi = [0,1]).
II. Each neuron has a predetermined threshold,
III. The neuron receives several inputs from excitatory synapses, all of which are assumed to have the same weights, which are all positive integers.

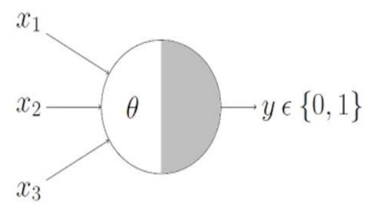
IV. The neurons are updated at the same time by summing the weighted excitatory inputs an setting the output (Vi) to 1 if "the sum is larger than or equal to the threshold" AND "the neuron has no inhibitory input."

The output rule for the McCullough-Pitts model is as follows:



This is where it all began..

M-P Neuron: A Concise Representation



Input Signals: Binary input signals (0 or 1) are applied to the neuron.

This representation just denotes that, for the Boolean inputs *x_1*, *x_2* and *x_3* if the *g***(x)** i.e., **sum ≥ theta**, the neuron will fire otherwise, it won't.

Weighted Summation: The inputs are multiplied by their corresponding weights, and the products are summed using the summation function (Σ).

Threshold Comparison: The result of the summation (Σ) is compared to the threshold value (θ).

Output Determination: If the summation (Σ) is greater than or equal to the threshold (θ), the neuron fires, and its output is set to 1. If Σ is less than θ, the neuron remains inactive, and its output is 0.

The McCulloch-Pitts neuron model essentially implements a simple form of threshold-based decision-making. It takes binary inputs, computes a weighted sum of these inputs, and produces an output based on whether the sum exceeds a predefined threshold. This model was influential in the development of early artificial neural networks and served as a foundation for more complex neuron models and neural network architectures.

Question 1.3: Discuss (including images for illustration) how the pioneers in the AI field did imitate the human biological brain system to conceive the first artificial neural networks.

The neural network and the brain have a lot in common because neurons are the most fundamental unit of both the nervous system and the neural network. The input to a biological neural network comes from dendrites, while the output comes from the axon. In an artificial neural network, on the other hand, the input is immediately sent to a neuron, and the output is also directly received from the neuron.

Although the method of learning is different, the learning in both neural networks is comparable at a very abstract level. Gradient descent is used in artificial neural networks, which necessitates back propagation. Hebbian learning is used in biological neural networks, where one neuron can trigger another neuron in a variety of ways.

Modern Deep Learning (2000s - Present): Models: Researchers have developed increasingly sophisticated neural network architectures, including Convolutional Neural Networks (CNNs) for image recognition, Recurrent Neural Networks (RNNs) for sequence data, and Transformer models for natural language processing.

Deep learning's origins and pioneers. (2018, May 8). McKinsey & Company. https://www.mckinsey.com/featured-insights/artificial-intelligence/deep-learnings-origins-and-pioneers

Chandra, A. L. (2022, September 27). McCulloch-Pitts Neuron — Mankind's First Mathematical Model of a Biological Neuron. Medium. https://towardsdatascience.com/mcculloch-pitts-model-5fdf65ac5dd1

PART II: Linear Algebra for Deep Learning: Matrices (20 Points

Given the following Matrices.

$$\mathbf{A} = \begin{bmatrix} 5 & 3 & 8 \\ 2 & -1 & 7 \end{bmatrix}$$

B =?

--) It is assumed that the student plans to perform the dot multiplication A * B.

--) Provide a matrix B whose elements are all scalar so that the dot multiplication can be done.

--) Perform the dot multiplication A * B

Answer:

To perform the dot between matrices A and B, the number of columns in matrix A must be equal to the number of rows in matrix B. In your case,

$$\mathbf{B} = \begin{bmatrix} 2 & 3 \\ 1 & 5 \\ 2 & 3 \end{bmatrix}$$

$$C = \begin{bmatrix} 5*2+3*1+8*2 & 5*3+3*5+8*3\ 3 \\ 2*2+(-1*1)+7*2 & 2*3+(-1*5)+7*3 \end{bmatrix}$$

$$C = \begin{bmatrix} 23 & 54 \\ 17 & 22 \end{bmatrix}$$

Given A is 2x3 and B= 3x2 matrix,

So, the multiplication of these matrices would result in C =2x2 matrix

The multiplication steps:

- The first step to find the first number in C, is to multiply all the elements in the first row of the matrix A with all the elements in the first column of the matrix B.
- The second step to find the second number in C, is to multiply all the elements in the first row of the matrix A with all the elements in the second column of the matrix B.

4. PART III: Linear Algebra for Deep Learning: Matrices (30 Points)

Given the following matrix as a 2D array:

$$\begin{bmatrix} 2 & 1 & 3 & 4 & 5 \\ 0 & 0 & 1 & 4 & 2 \\ 4 & 2 & 6 & 8 & 10 \\ 6 & 3 & 14 & 35 & 33 \end{bmatrix}$$

Answer: Each row of the matrix is a separate vector. So, it has 4 vectors.

Vector 1= [2 1 3 4 5]

Vector 2= [0 0 1 4 2]

Vector 3= [4 2 6 8 10]

Vector 4= [6 3 14 35 33]

Question 3.2: Let's consider this matrix as a vector of vectors.
Add 3 to the element vector (of the matrix) at the index = 1. The addition is performed elementwise along Axis 1.
Display the matrix with all its scalar elements after the operation has been done in the format of a 2D matrix.

Let us consider that the given matrix has vectors of vectors.
The vector that is at the index=1 is [0, 0, 1, 4, 2]

Adding 3 to the element vector (of the matrix) at the index 1 would result in
[3, 3, 4, 7, 5]

The Resultant matrix with all its scalar elements after the operation has been done in the format of a 2Dmatrix.

$$\begin{bmatrix} 2 & 1 & 3 & 4 & 5 \\ 3 & 3 & 4 & 7 & 5 \\ 4 & 2 & 6 & 8 & 10 \\ 6 & 3 & 14 & 35 & 33 \end{bmatrix}$$

Adding 2 we will add.

Question 3.3: Continuing from Question 3.2, i.e., after the above addition of 3 has been done: Flatten the matrix and display the result.

The matrix before flattening is $\begin{bmatrix} 2 & 1 & 3 & 4 & 5 \\ 3 & 3 & 4 & 7 & 5 \\ 4 & 2 & 6 & 8 & 10 \\ 6 & 3 & 14 & 35 & 33 \end{bmatrix}$

The resultant matrix after flattening is [[2,1,3,4,5], [3,3,4,7,5], [4,2,6,8,10], [6,3,14,35,33]]

PART IV: TensorFlow Code in Jupyter Notebook (20 Points)