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ARTIFICIAL INTELLIGENCE II

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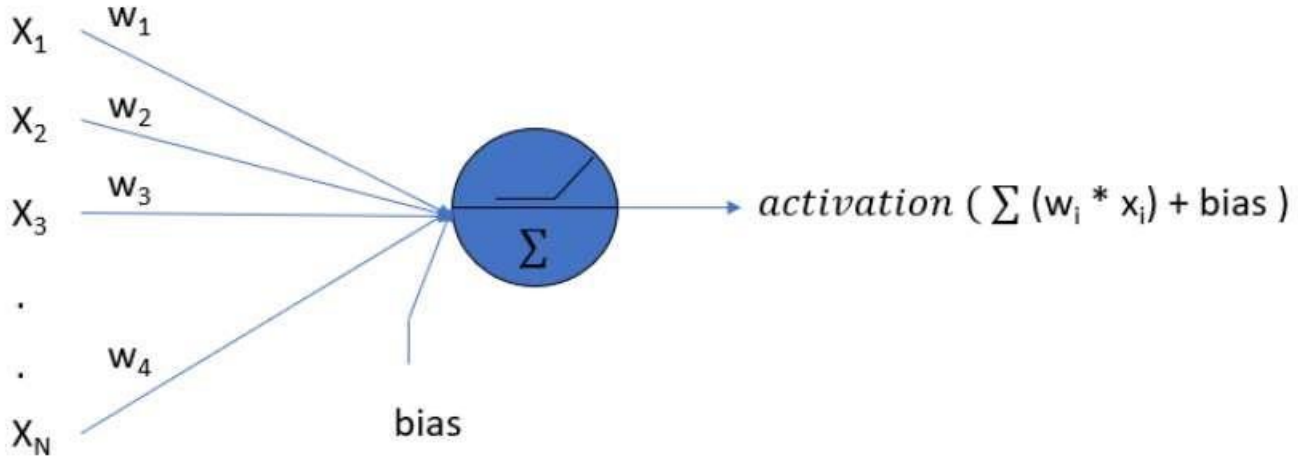
DIGITAL LEARNING CONTENT

CHAPTER-5

Neural Networks

What are Neural Networks ?

Neural networks mimic the basic functioning of the human brain and are inspired by how the human brain interprets information. They solve various real-time tasks because of its ability to perform computations quickly and its fast responses.



A single neuron shown with X_i inputs with their respective weights W_i and a bias term and applied activation function

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What are Neural Networks ?

Artificial Neural Network has a huge number of interconnected processing elements, also known as Nodes. These nodes are connected with other nodes using a connection link. The connection link contains weights, these weights contain the information about the input signal. Each iteration and input in turn leads to updating of these weights. After inputting all the data instances from the training data set, the final weights of the Neural Network along with its architecture is known as the Trained Neural Network. This process is called Training of Neural Networks.

These trained neural networks solve specific problems as defined in the problem statement.

What are Neural Networks Used For?

Neural networks are employed across various domains for:
Identifying objects, faces, and understanding spoken language in applications like self-driving cars and voice assistants.
Analyzing and understanding human language, enabling sentiment analysis, chat bots, language translation, and text generation.
Diagnosing diseases from medical images, predicting patient outcomes, and drug discovery.
Predicting stock prices, credit risk assessment, fraud detection, and algorithmic trading.
Personalizing content and recommendations in e-commerce, streaming platforms, and social media.
Powering robotics and autonomous vehicles by processing sensor data and making real-time decisions.

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What are Neural Networks Used For?

Enhancing game AI, generating realistic graphics, and creating immersive virtual environments.

Monitoring and optimizing manufacturing processes, predictive maintenance, and quality control.

Analyzing complex datasets, simulating scientific phenomena, and aiding in research across disciplines.

Generating music, art, and other creative content.

Advantages of Neural Networks

There are various advantages of neural networks, some of which are discussed below:

1) Store information on the entire network

Just like it happens in traditional programming where information is stored on the network and not on a database. If a few pieces of information disappear from one place, it does not stop the whole network from functioning.

2) The ability to work with insufficient knowledge:

After the training of ANN, the output produced by the data can be incomplete or insufficient. The importance of that missing information determines the lack of performance.

Advantages of Neural Networks

3) Good falt tolerance:
The output generation is not affected by the corruption of one or more than one cell of artificial neural network. This makes the networks better at tolerating faults.

4) Distributed memory:
For an artificial neural network to become able to learn, it is necessary to outline the examples and to teach it according to the output that is desired by showing those examples to the network. The progress of the network is directly proportional to the instances that are selected.

5) Gradual Corruption:
Indeed a network experiences relative degradation and slows over time. But it does not immediately corrode the network.

Advantages of Neural Networks

6) Ability to train machine:
ANN learn from events and make decisions through commenting on similar events.

7) The ability of parallel processing:
These networks have numerical strength which makes them capable of performing more than one function at a time.

Disadvantages of Neural Networks

These algorithms are designed to recognize preferences and leave the unimportant ones to determine the output. These preferences can differ at different times resulting in a different decision. A computer-dependent decision is based on a fraction of essential qualities/values/requirements at a given time. These approximate results may lead to wrong decisions. Due to its complex nature, there are several **disadvantages of Neural Networks** that need to rectified.

1. Hardware dependent

Although the data is stored online, artificial networks still require hardware to create them in the first place. The hardware cost increases with the complexity of the problem, and its setup requires additional efforts to maintain them.

Disadvantages of Neural Networks

2. Complex Algorithms are foreseen disadvantages of Neural Networks

All the programming needed to be done initially requires lengthy and complex programs to be written. For example, it may require months to create an algorithm capable of working a specified task.

3. Black Box Nature

Even when the results are accurate human analysts can't track and check the derivations. Most neural networks are black-box systems generating results based on experience and not on specified programs, making it difficult for modifications.

Disadvantages of Neural Networks

4. Approximate Results

Various theorems are used to give only a probable value. All the theories used are not entirely suitable to give results possible for all situations, and the desired output may not be obtained. This uncertainty is among the eye-opening **problems with Neural Networks**.

5. Data-dependency

Whatever data is fed to the machine, it acts accordingly. The more amount of data is used during training, the more accurate the results are. Dependency on data is one of the leading disadvantages of Neural Networks, as some have to be on the maintenance side to watch it. Since there are errors in the data, the result will be faulty, which poses serious threats.

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Biological Neural Networks

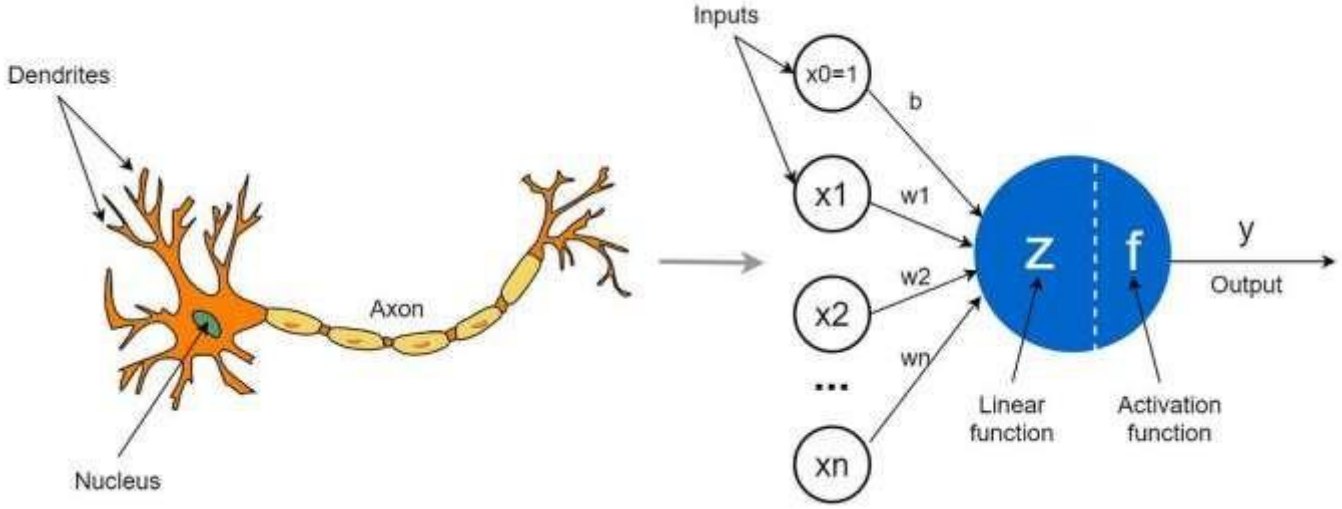
Biological Neural Network (BNN) is a structure that consists of Synapse, dendrites, cell body, and axon. In this neural network, the processing is carried out by neurons. Dendrites receive signals from other neurons, Soma sums all the incoming signals and axon transmits the signals to other cells.

Some advantages of BNN :
The synapses are the input processing element.
It is able to process highly complex parallel inputs.

Some disadvantages of BNN :
There is no controlling mechanism.
Speed of processing is slow being it is complex.

Biological Neural Networks

Neurons: In both BNNs and ANNs, neurons are the basic building blocks that process and transmit information. However, BNN neurons are more complex and diverse than ANNs. In BNNs, neurons have multiple **dendrites** that receive input from multiple sources, and the **axons** transmit signals to other neurons, while in ANNs, neurons are simplified and usually only have a single output.



Biological Neural Networks

The brain is principally composed of about **10 billion neurons**, each connected to about 10,000 other neurons. Each of the yellow blobs in the picture above are neuronal cell bodies (soma), and the lines are the input and output channels (dendrites and axons) which connect them.

Each neuron receives **electrochemical inputs** from other neurons at the dendrites. If the sum of these electrical inputs is sufficiently powerful to activate the neuron, it transmits an electrochemical signal along the axon, and passes this signal to the other neurons whose dendrites are attached at any of the axon terminals. These attached neurons may then fire.

It is important to note that a **neuron fires only if the total signal received at the cell body exceeds a certain level.** The neuron either fires or it doesn't, there aren't different grades of firing.

Biological Neural Networks

So, our entire brain is composed of these interconnected electro-chemical transmitting neurons. From a very large number of extremely simple processing units (each performing a weighted sum of its inputs, and then firing a binary signal if the total input exceeds a certain level) the brain manages to perform extremely complex tasks.

This is the model on which artificial neural networks are based. Thus far, artificial neural networks haven't even come close to modeling the complexity of the brain, but they have shown to be good at problems which are easy for a human but difficult for a traditional computer, such as image recognition and predictions based on past knowledge.

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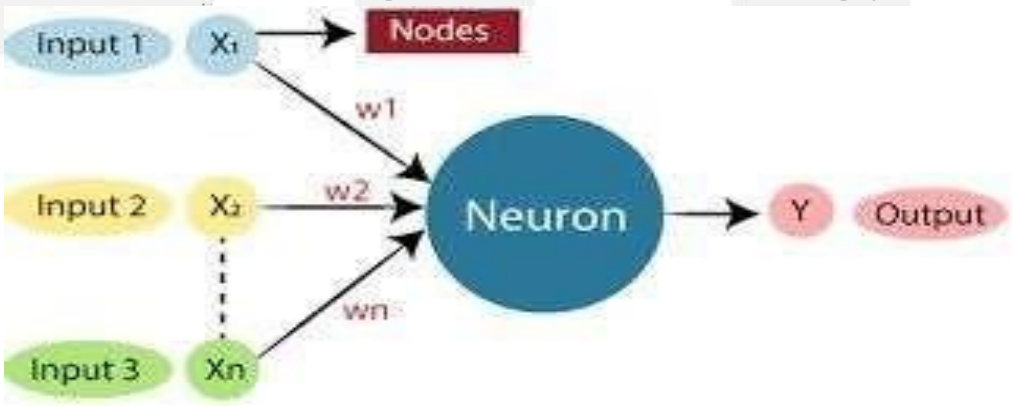
Artificial Neural Networks

An artificial neuron is a connection point in an artificial neural network. Artificial neural networks, like the human body's biological neural network, have a layered architecture and each network node (connection point) has the capability to process input and forward output to other nodes in the network. In both artificial and biological architectures, the nodes are called neurons and the connections are characterized by synaptic weights, which represent the significance of the connection. As new data is received and processed, the synaptic weights change and this is how learning occurs.

Artificial Neural Networks

Artificial neurons are modeled after the hierarchical arrangement of neurons in biological sensory systems. In the visual system, for example, light input passes through neurons in successive layers of the retina before being passed to neurons in the thalamus of the brain and then on to neurons in the brain's visual cortex. As the neurons pass signals through an increasing number of layers, the brain progressively extracts more information until it is confident it can identify what the person is seeing. In artificial intelligence, this fine tuning process is known as deep learning.



Artificial Neural Networks

In both artificial and biological networks, when neurons process the input they receive, they decide whether the output should be passed on to the next layer as input. The decision of whether or not to send information on is called bias and it's determined by an activation function built into the system. For example, an artificial neuron may only pass an output signal on to the next layer if its inputs (which are actually voltages) sum to a value above some particular threshold value. Because activation functions can either be linear or non-linear, neurons will often have a wide range of convergence and divergence. Divergence is the ability for one neuron to communicate with many other neurons in the network and convergence is the ability for one neuron to receive input from many other neurons in the network.

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Network Architectures

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the brain. ANNs, like people, learn by examples. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process. Learning largely involves adjustments to the synaptic connections that exist between the neurons.
Artificial Neural Networks (ANNs) are a type of machine learning model that are inspired by the structure and function of the human brain. They consist of layers of interconnected “neurons” that process and transmit information.

There are several different architectures for ANNs, each with their own strengths and weaknesses. Some of the most common architectures include:

Artificial Neural Network Architectures

Feedforward Neural Networks: This is the simplest type of ANN architecture, where the information flows in one direction from input to output. The layers are fully connected, meaning each neuron in a layer is connected to all the neurons in the next layer.

Recurrent Neural Networks (RNNs): These networks have a “memory” component, where information can flow in cycles through the network. This allows the network to process sequences of data, such as time series or speech.

Convolutional Neural Networks (CNNs): These networks are designed to process data with a grid-like topology, such as images. The layers consist of convolutional layers, which learn to detect specific features in the data, and pooling layers, which reduce the spatial dimensions of the data.

Artificial Neural Network Architectures

The model of an artificial neural network can be specified by these entities:

- **Interconnections**
- **Activation functions**

Interconnections:

Interconnection can be defined as the way processing elements (Neuron) in ANN are connected to each other. Hence, the arrangements of these processing elements and geometry of interconnections are very essential in ANN.

These arrangements always have two layers that are common to all network architectures, the Input layer and output layer where the input layer buffers the input signal, and the output layer generates the output of the network.

Artificial Neural Network Architectures

The third layer is the Hidden layer, in which neurons are neither kept in the input layer nor in the output layer. These neurons are hidden from the people who are interfacing with the system and act as a black box to them. By increasing the hidden layers with neurons, the system's computational and processing power can be increased but the training phenomena of the system get more complex at the same time.

There exist five basic types of neuron connection architecture :

Single-layer feed-forward network

Multilayer feed-forward network

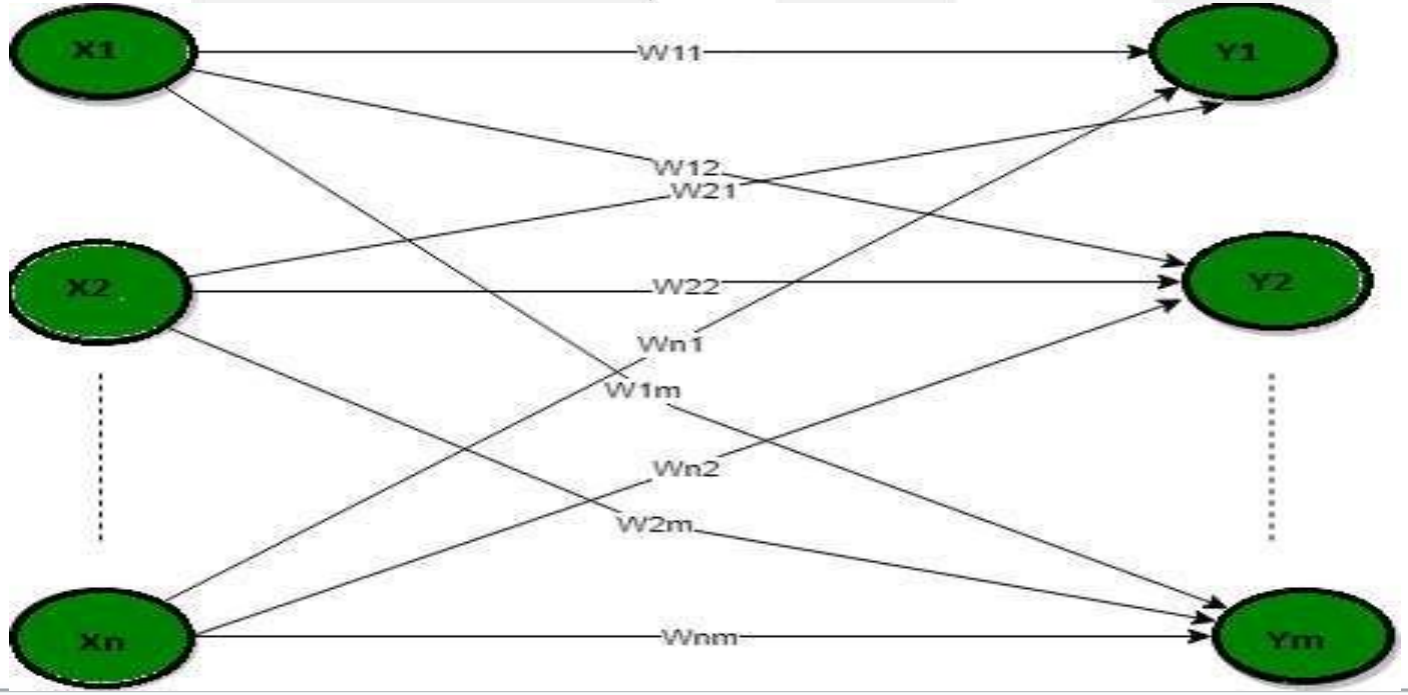
Single node with its own feedback

Single-layer recurrent network

Multilayer recurrent network

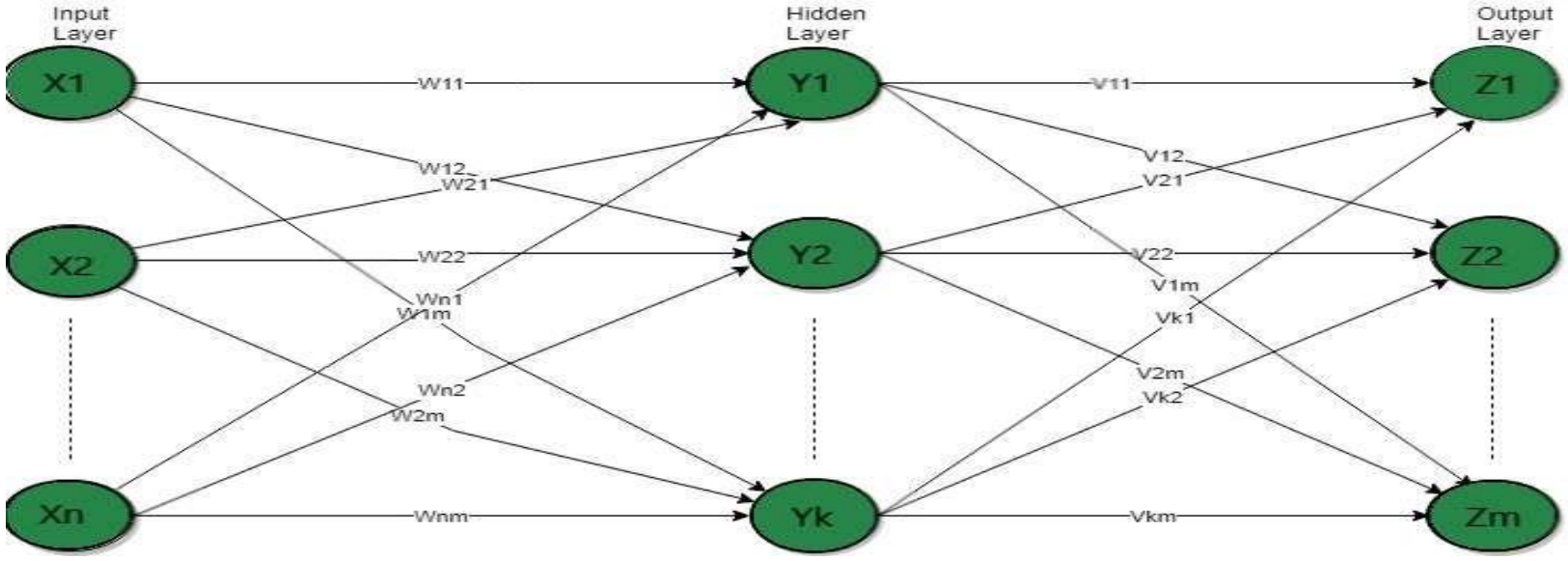
Single-layer feed-forward network

In this type of network, we have only two layers input layer and the output layer but the input layer does not count because no computation is performed in this layer. The output layer is formed when different weights are applied to input nodes and the cumulative effect per node is taken. After this, the neurons collectively give the output layer to compute the output signals.



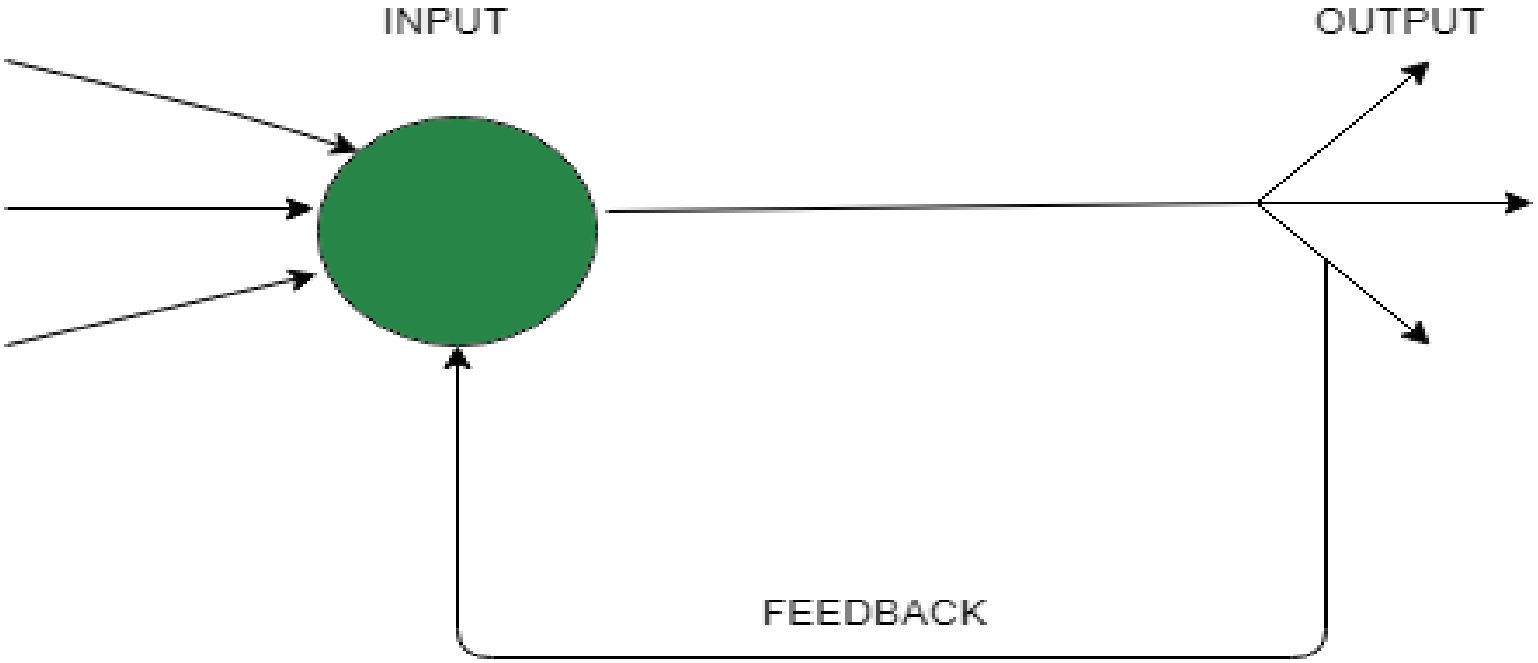
Multilayer feed-forward network

This layer also has a hidden layer that is internal to the network and has no direct contact with the external layer. The existence of one or more hidden layers enables the network to be computationally stronger, a feed-forward network because of information flow through the input function, and the intermediate computations used to determine the output Z. There are no feedback connections in which outputs of the model are fed back into itself.



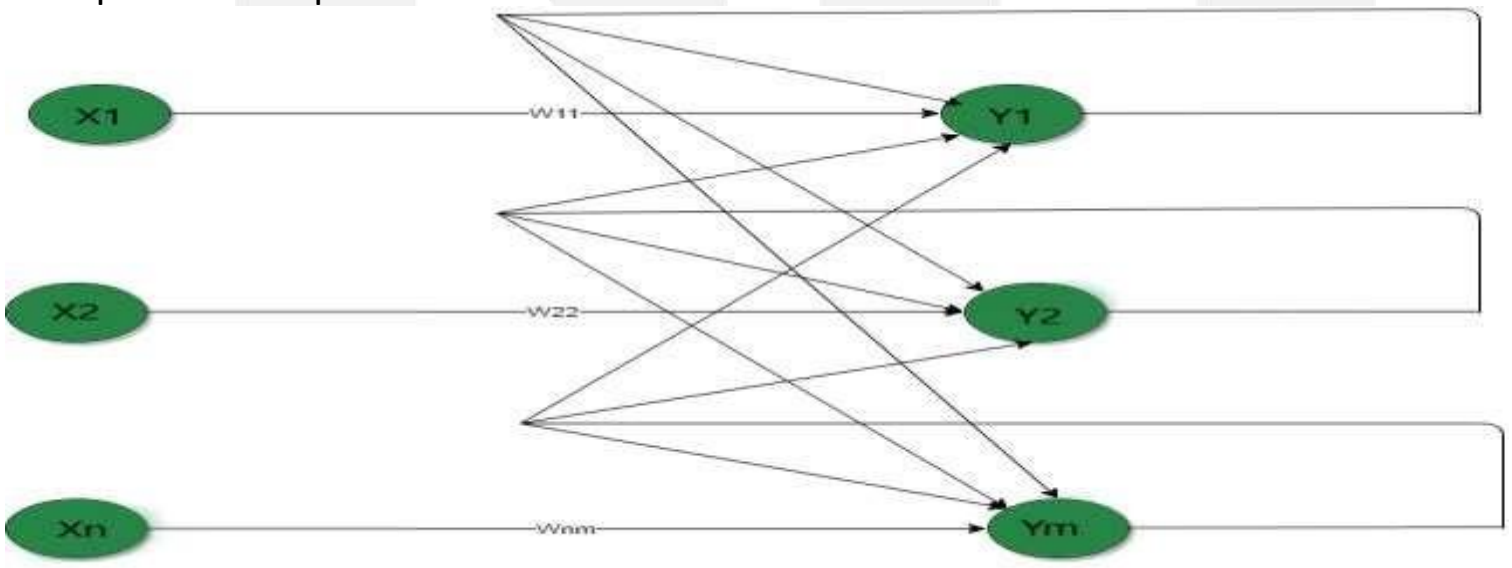
Single node with its own feedback

When outputs can be directed back as inputs to the same layer or preceding layer nodes, then it results in feedback networks. Recurrent networks are feedback networks with closed loops. The above figure shows a single recurrent network having a single neuron with feedback to itself.



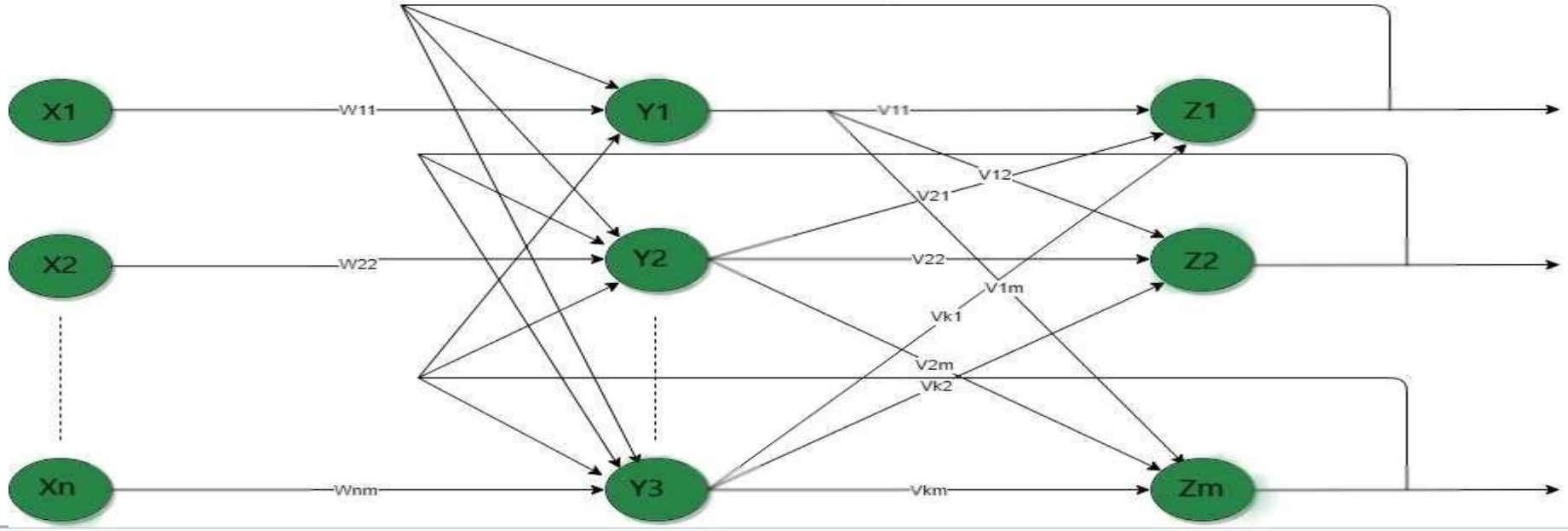
Single-layer recurrent network

The above network is a single-layer network with a feedback connection in which the processing element's output can be directed back to itself or to another processing element or both. A recurrent neural network is a class of artificial neural networks where connections between nodes form a directed graph along a sequence. This allows it to exhibit dynamic temporal behavior for a time sequence. Unlike feedforward neural networks, RNNs can use their internal state (memory) to process sequences of inputs.



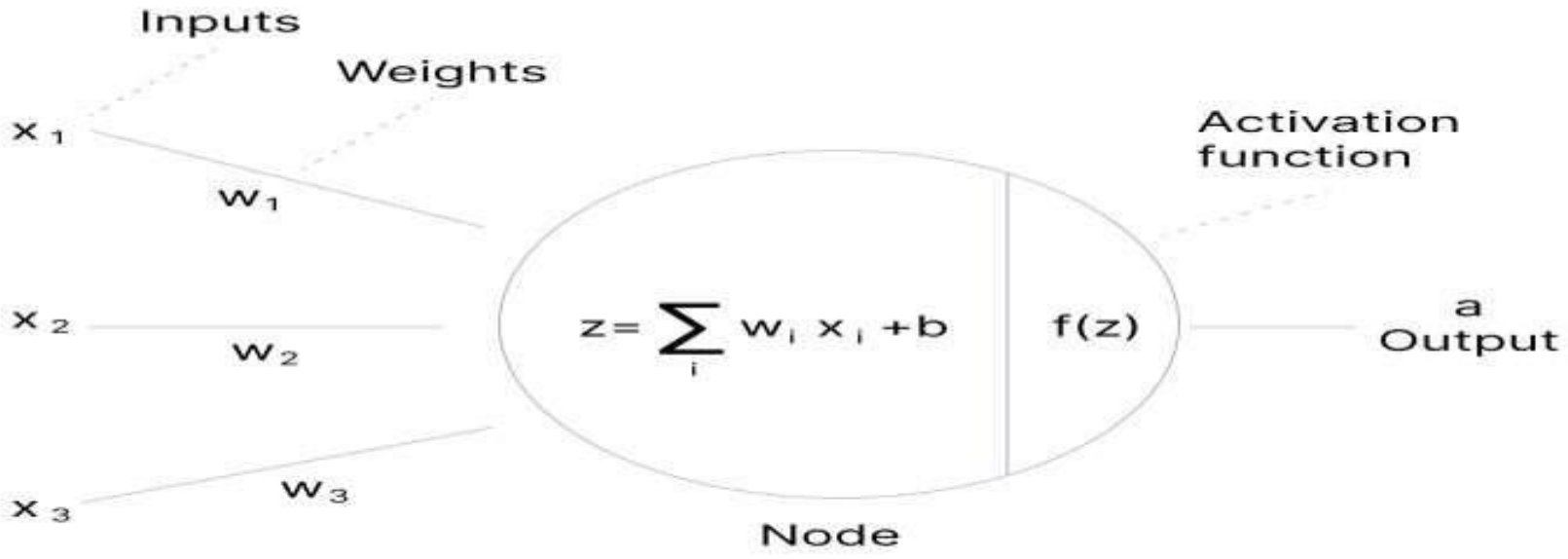
Multilayer recurrent network

In this type of network, processing element output can be directed to the processing element in the same layer and in the preceding layer forming a multilayer recurrent network. They perform the same task for every element of a sequence, with the output being dependent on the previous computations. Inputs are not needed at each time step. The main feature of a Recurrent Neural Network is its hidden state, which captures some information about a sequence.



Activation Function

An Activation Function decides whether a neuron should be activated or not. This means that it will decide whether the neuron's input to the network is important or not in the process of prediction using simpler mathematical operations.



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Applications of Neural Networks

Neural Networks are regulating some key sectors including finance, healthcare, and automotive. As these artificial neurons function in a way similar to the human brain. They can be used for image recognition, character recognition and stock market predictions.

1. <u>Facial Recognition</u>

Facial Recognition Systems are serving as robust systems of surveillance. Recognition Systems matches the human face and compares it with the digital images. They are used in offices for selective entries. The systems thus authenticate a human face and match it up with the list of IDs that are present in its database.

Convolutional Neural Networks (CNN) are used for **facial recognition and image processing.** Large number of pictures are fed into the database for training a neural network. The collected images are further processed for training.

Sampling layers in CNN are used for proper evaluations. Models are optimized for accurate recognition results.

Applications of Neural Networks

2. <u>Stock Market Prediction</u>

Investments are subject to market risks. It is nearly impossible to predict the upcoming changes in the highly volatile stock market. The forever changing bullish and bearish phases were unpredictable before the advent of neural networks. But well what changed it all? Neural Networks of course…

To make a successful stock prediction in real time a **Multilayer Perceptron MLP** *(class of feed forward artificial intelligence algorithm)* is employed. MLP comprises multiple layers of nodes, each of these layers is fully connected to the succeeding nodes. Stock's past performances, annual returns, and non profit ratios are considered for building the MLP model.

3. <u>Social Media</u>

No matter how cliché it may sound, social media has altered the normal boring course of life. Artificial Neural Networks are used to study the behaviors of social media users. Data shared everyday via virtual conversations is tacked up and analyzed for competitive analysis.
Neural networks duplicate the behaviors of social media users. Post analysis of individuals' behaviors via social media networks the data can be linked to people's spending habits. **Multilayer Perceptron ANN** is used to mine data from social media applications.

Applications of Neural Networks

4. <u>Aerospace</u>

Aerospace Engineering is an expansive term that covers developments in spacecraft and aircraft. Fault diagnosis, high performance auto piloting, securing the aircraft control systems, and modeling key dynamic simulations are some of the key areas that neural networks have taken over. Time delay Neural networks can be employed for modeling non linear time dynamic systems.

Time Delay Neural Networks are used for **position independent feature recognition.** The algorithm thus built based on time delay neural networks can recognize patterns. *(Recognizing patterns are automatically built by neural networks by copying the original data from feature units).*

Other than this TNN are also used to provide stronger dynamics to the NN models. As passenger safety is of utmost importance inside an aircraft, algorithms built using the neural network systems ensures the accuracy in the autopilot system. As most of the autopilot functions are automated, it is important to ensure a way that maximizes the security.

Applications of Neural Networks

5. Defence

Defence is the backbone of every country. Every country's state in the international domain is assessed by its military operations. Neural Networks also shape the defence operations of technologically advanced countries. The United States of America, Britain, and Japan are some countries that use artificial neural networks for developing an active defence strategy.

Neural networks are used in logistics, armed attack analysis, and for object location. They are also used in air patrols, maritime patrol, and for controlling automated drones. The defence sector is getting the much needed kick of artificial intelligence to scale up its technologies.

Convolutional Neural Networks(CNN), are employed for determining the presence of underwater mines. Underwater mines are the underpass that serve as an illegal commute route between two countries. **Unmanned Airborne Vehicle (UAV),** and **Unmanned Undersea Vehicle (UUV)** these autonomous sea vehicles use convolutional neural networks for the image processing.

Convolutional layers form the basis of Convolutional Neural Networks. These layers use different filters for differentiating between images. Layers also have bigger filters that filter channels for image extraction.

Applications of Neural Networks

6. Healthcare

The age old saying goes like "Health is Wealth". Modern day individuals are leveraging the advantages of technology in the healthcare sector. **Convolutional Neural Networks** are actively employed in the healthcare industry for **X ray detection, CT Scan** and **ultrasound.**

As CNN is used in image processing, the medical imaging data retrieved from aforementioned tests is analyzed and assessed based on neural network models. **Recurrent Neural Network (RNN)** is also being employed for the development of voice recognition systems.

Voice recognition systems are used these days to keep track of the patient's data. Researchers are also employing **Generative Neural Networks** for drug discovery. Matching different categories of drugs is a hefty task, but generative neural networks have broken down the hefty task of drug discovery. They can be used for combining different elements which forms the basis of drug discovery.

Applications of Neural Networks

7. <u>Signature Verification and Handwriting Analysis</u>

Signature Verification , as the self explanatory term goes, is used for verifying an individual's signature. Banks, and other financial institutions use signature verification to cross check the identity of an individual.

Usually a signature verification software is used to examine the signatures. As cases of forgery are pretty common in financial institutions, signature verification is an important factor that seeks to closely examine the authenticity of signed documents.

Artificial Neural Networks are used for **verifying the signatures.** ANN are trained to recognize the difference between real and forged signatures. ANNs can be used for the verification of both offline and online signatures.

For training an ANN model, varied datasets are fed in the database. The data thus fed help the ANN model to differentiate. **ANN model employs image processing** for extraction of features.

Applications of Neural Networks

8. <u>Weather Forecasting</u>

The forecasts done by the meteorological department were never accurate before artificial intelligence came into force. Weather Forecasting is primarily undertaken to anticipate the upcoming weather conditions beforehand. In the modern era, weather forecasts are even used to predict the possibilities of natural disasters.

Multilayer Perceptron (MLP), Convolutional Neural Network (CNN) and Recurrent Neural Networks (RNN) are used for weather forecasting. Traditional ANN multilayer models can also be used to predict climatic conditions 15 days in advance. A combination of different types of neural network architecture can be used to predict air temperatures.

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