Report on Neural Networks

Introduction

In machine learning, a neural network, or artificial neural network (ANN), is a computational model based on how biological neural networks found in animal brains function. Artificial neural networks are crucial in artificial intelligence and particularly in machine learning.

Basic Architecture and Components

1. Neurons: Neural networks consist of many neurons, or nodes. These nodes aim to mimic the neuron cells found in brains. Each neuron processes the input from the previous layer, applies an activation function (discussed below). It then adjusts its weights based on the error between the predicted and actual output during training, which improves the model's accuracy. (Cloudflare, 2024).

2. Layers: In neural networks, there are three primary types of layers. A neural network must have at least one of each and can have multiple 'hidden' layers. The layers are:

a) *An Input Layer:* Information passes into the artificial neural network from the input layer. Input nodes process the data and then pass it on to the next layer.

b) *Several "Hidden" Layers:* These take their input from the previous, processes it further, and passes it on to the next layer. Artificial neural networks can have anywhere from 1 hidden layer to many of these hidden layers.

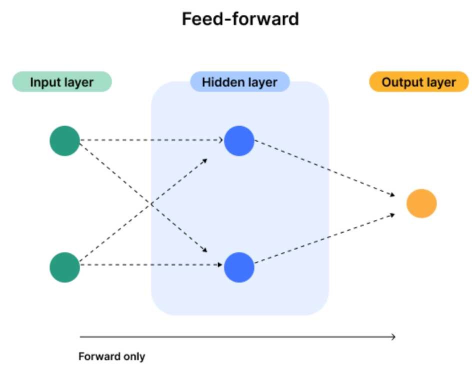
c) *An Output Layer:* The output layer produces the result of the data processing by all previous layers of the ANN. It can have single or multiple nodes. An example of a single output node is a binary classification problem (outputs 0 or 1), whereas a multi-class classification would have more than 1 output node in this layer (Amazon Web Services, 2024).

3. Activation Functions: The mathematical function that is applied to the weighted total of the input plus bias for every neuron. To prevent a neural network from behaving like a linear regression model, it attempts to add non-linearity into the model, and this helps the network in learning and representing complicated patterns in the data. By determining the weighted sum and then applying bias, the activation function determines if a neuron should be activated or not. (Geeks for Geeks, 2024).

Activation functions include:

- Sigmoid Function: Transforms input to a number between 0 and 1. It can be used for binary classification (above 0.5 becomes 1 and otherwise 0).
- Rectified Linear Unit (ReLU): This is the most commonly used activation function and outputs x if it is positive and otherwise it outputs 0. ReLU is used in hidden layers because it is simple and efficient.
- Tangent Hyperbolic function (Tanh): It’s a mathematically shifted version of the sigmoid function. It transforms inputs to a range between -1 and 1 and thus is used to center data. This means that the next can learn much more easily.

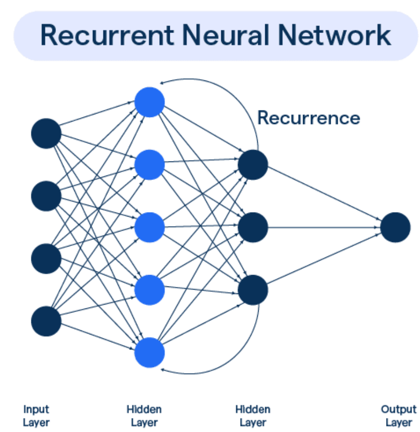
Types and Applications of Neural Networks



1. Feedforward Neural Networks (FNNs): In feedforward neural networks, nodes can only pass information to nodes in front. They are used for simpler tasks such as natural language processing, image classification or regression problems. An example of feed-forward neural networks is a handwriting image recognition application.

2. Convolutional Neural Networks (CNNs): CNNs are like feedforward networks but mainly utilised for processing visual data like images by using a process called convolution. This involves applying kernels to the image through matrix multiplication to identify features such as edges, textures, and shapes. This makes CNNs particularly useful for image recognition, pattern recognition, or computer vision (IBM, 2024). An example use of CNNs is in facial recognition systems and self-driving car technology to identify objects in real-time.

3. Recurrent Neural Networks (RNNs): These neural networks use feedback loops and are primarily utilised when handling time-series data (data recorded over consistent periods of time) to make predictions about future outcomes. One particularly useful application of recurrent neural networks is in stock market prediction or sales forecasting.



Training Process of Neural Networks

Training neural networks is teaching a neural network to perform a task. These ANNs learn by initially processing large sets of (labeled or unlabeled) data. Effectively, these are examples that teach the neural network to process unknown inputs more accurately. The steps to training an ANN are detailed below.

1. Backpropagation: This is a key algorithm that has two sub-steps:

- *Forward Pass:* Input/training data passes through the network, and predictions are made based on current weights.
- *Backward Pass:* The error between the predicted and actual outputs is calculated. The error is then propagated backward through the network to update the weights using gradient descent, which is an iterative process that minimises errors between predicted and actual results. (IBM, 2024).

2. Optimisation Techniques: There are several optimisation techniques that improve the training process. These include:

- **Gradient Descent**: This important optimisation approach reduces errors between expected and observed outputs. Stochastic Gradient Descent and Mini-Batch Gradient Descent are two examples of gradient descent subtypes.
- **Adam Optimiser:** AdaGrad and RMSProp, two extensions of stochastic gradient descent, are combined into one adaptive learning rate optimisation technique called Adam Optimiser (Machine Learning Mastery, 2021). It adjusts learning rates based on the moments of the gradients (Keras, n.d.)

3. Loss Functions:

Loss functions measure the difference between the expected values and the actual values from the training data.

- **Mean Squared Error:** This is a tool that finds the average squared difference (to get a positive value) between the values that were predicted and the ones in the data given to the model.
- **Cross-Entropy Loss:** A value between 0 and 1 that evaluates the performance of the (categoristaion) models worked (Datacamp, 2023).

Conclusion

An essential part of artificial intelligence is artificial neural networks. These replicate the structure of the brain. This involves many nodes or neurons, an input layer, several hidden layers and an output layer, and activation functions. There are many types of ANNs which include feed-forward, convolutional and recurrent, which all have slightly different methods and applications. The training process for artificial neural networks involves backpropagation, various optimisation techniques and the use of loss functions.

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