A Neural Network from Scratch

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# 1 Introduction

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. [2] A Neural network is configured to recognize the pattern or to classify the data. Unlike conventional computing, Neural Network learns from the given set of examples. In this project, we implemented an Artificial Neural Network for the task of digit classification without using any advanced libraries. Digit classification has been a fertile ground for exploring several learning techniques ranging from automatically learning feature representations, learning classifiers invariant to distortions, matching and alignment based distances, and learning multilayered representations of data. [1] A neural network can be defined as “Neural computing is the study of networks of adaptable nodes which, through a process of learning from task examples, store experiential knowledge and make it available for use.” [3] A NN consists input layer, hidden layer, and output layer. Neural Networks are modeled as collections of neurons that are connected in an acyclic graph. In other words, the outputs of some neurons can become inputs to other neurons. In a convolutional NN, learnable weights and bias are associated with Neurons. Since neural networks are best at identifying patterns or trends in data, they are well suited for prediction or forecasting needs including but not limited to sales forecasting, business marketing, customer research, data validation, risk management, medicine, robot learning etc.

# 2 Background

## 2.1 Stochastic Gradient Descent

Stochastic gradient descent (SGD) is a stochastic approximation of the gradient descent optimization and an iterative method for minimizing the loss function. Loss is defined as some kind of difference between the predicted output and the desired output. It is an iterative method in which the network is modified after each training sample is fed through the network and thus updating the network parameter in the direction in which the loss is minimised. SGD computes the gradient using a single sample and is much faster than the traditional batch descent algorithm. Large datasets often can't be held in RAM, which makes vectorization much less efficient. Rather, each sample or batch of samples must be loaded, worked with and the results are stored. This is computationally less expensive and also SGD is most useful when the objective function is non-convex. An objective function is termed non-convex if it has more than one local minima. In batch gradient descent we step down the true gradient and thus may eventually converge to a local minima. SGD is better in finding the global minima. SGD involves two main steps: Forward Propagation and Backpropagation.

## 2.3 Forward Propagation

As discussed before, an artificial neural network (ANN) consists of an input layer, an output layer, and any number of hidden layers situated between the input and output layers. The feed-forward computations performed by the ANN are as follows: The signals from the input layer are multiplied by a set of fully-connected weights connecting the input layer to the hidden layer. These weighted signals are then summed and combined with a bias. This calculation forms the pre-activation signal for the hidden layer. The pre-activation signal is then transformed by the hidden layer activation function to form the feed-forward activation signals leaving leaving the hidden layer. Similarly, the activations of the other hidden layers are calculated from the previous hidden layer. In a similar fashion, the hidden layer activation signals are multiplied by the weights connecting the hidden layer to the output layer, a bias is added, and the resulting signal is transformed by the output activation function to form the network output. The output is then compared to a desired target and the error between the two is calculated. This entire process is called feed forward propagation.

## 2.3 Back Propagation

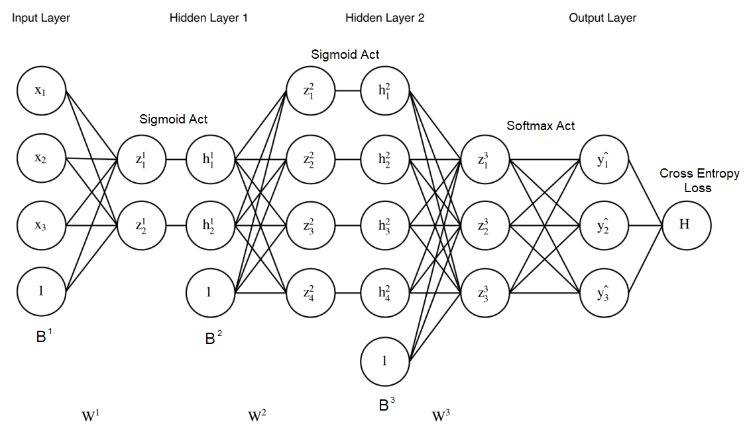
Backpropagation is the process of propagating the error that has been calculated at the end of forward propagation back through the network and update the network parameters so that the error is minimised. To do so, we make use of the chain rule to calculate the derivative of the loss with respect to parameters. Once we have the gradients of loss with respect to each of the network parameters, we update the parameter using a learning rate. This means that we change the values of the parameters in the direction in which the loss reduces.

Fig. 2. Structure of our Neural Network

# 3 IMPLEMENTATIONS

## 3.1 Architecture

In this project, we have implemented a neural network for the purpose of digit classification. Our implementation is in python and does not use any advanced libraries. There are two hidden layers with 256 neurons in each hidden layer and an output layer with 10 neurons corresponding to the ten digits from 0 to 9. The dataset that we have used in this project is the MNIST dataset in which each image is represented by 28 x 28 pixels. Each pixel’s value ranging from 0 to 255. We use these 784-pixel values to represent the input and to train the network. So, we have 784 neurons in the input layer. This constitutes the structure of our neural network.

## 3.2 Preparing the training data:

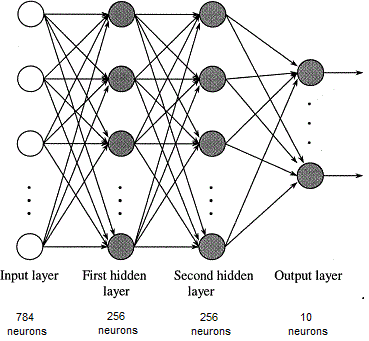


Fig. 1. Structure of our Neural Network

MNIST database of handwritten digits is used to train the network and to test the accuracy. The data is available in a byte format and we have used the python-mnist library to read the dataset which will return a list of all the images and the labels corresponding to each image. Each image returned by this library will be in the form of a list of 784 features corresponding to the 784 pixels with a value from 0 to 255. The label corresponding to that image is a number from 0 to 9. As the loss that we are about to calculate is categorical cross entropy, we have encoded the labels as one-hot vectors. So, that means a label of ‘2’ has been encoded as a list of 10 in which the second index is 1 and the rest are zeros i.e. [0,1,0,0,0,0,0,0,0,0]. This helps in comparison with the final output layer of the network in which only one neuron has to fire in an ideal situation.

There are 60000 images in the data set and we have sampled randomly 5000 out of them for the purpose of validation and 5000 for the purpose of testing. From the rest 50000, we have performed experiments changing the training size from 10000 to 50000. Since we have randomly sampled all the images, our assumption is that there are equal number of samples from each class in all the three splits. The image data has pixel values ranging from 0 to 255, so we have normalized each pixel value to be in the range [0,1] by dividing each value by 255. It makes the weak input weaker and the strong input stronger. This can be thought as each pixel either being on or off and it helps the algorithm to converge faster.

## 3.3 Network Parameters

We have defined six network parameters as follows:

*W1:* From input layer to the first hidden layer. Since input layer has 784 neurons and the first hidden layer has 256 neurons., this will be a 784 x 256 vector.

*B1:* This is the bias applied to each of the neuron in the first hidden layer, a 256 x 1 vector.

*W2:* From the first hidden layer to the second hidden layer. Since each of the hidden layers has 256 neurons, this will be a 256 x 256 vector.

*B2:* This is the bias applied to each of the neuron in the second hidden layer, a 256 x 1 vector.

*W3:* From the second hidden layer to the output layer. Since the second hidden layer has 256 neurons and the output layer has 10 neurons, this will be a 256 x 10 vector.

*B3:* This is the bias applied to each of the neuron in the output layer, a 10 x 1 vector.

Initially all the parameters are randomly initialised in the range of [0,1] with a mean of 0.5. However, we have observed that this initialisation lead to a very slow convergence and we have researched that initialising weights with a mean 0 would give us better results. So, we have initialised all the weights and biases in the range of [-1,1] with a mean of 0.

## 3.4 Stochastic Gradient Descent

We have implemented Stochastic Gradient Descent on each of the training sample in the training dataset. Each training sample is fed to the input and the output value is calculated through forward propagation. Then, using Back Propagation we have propagated the loss back to each layer and adjusted the weights and bias at each layer.

## 3.4 Forward Propagation

During forward propagation, at each of the hidden layers a sigmoid activation function is applied to each neuron in the hidden layers. For each of the output neuron, softmax activation is applied. The final output of the network is the result of this softmax activation and is used in estimating the loss and thus propagating the loss back through the network.

## 3.4 Dropout

To implement dropout in this network, we have defined a parameter called dropout rate and an element wise multiplication of each of the neuron in the hidden layer with a 256 x 1 mask generated out of a binomial distribution with dropout rate as its parameter. Our dropout rate parameter indicates the proportion of the number of hidden units retained.

## 3.4 Back Propagation

The error between the predicted output and the actual label which is encoded as a one hot vector is back propagated and the partial derivatives of the loss with respect to each of the network parameters are calculated. A learning rate of 0.1 is used initially, and it is decayed after every 5000 epochs at a rate of 0.005. Finally, the learning rate is fixed at 0.001.

After the partial derivatives of the loss with respect to the network parameters are determined, the parameters are updated.

Update step: H is the cross entropy loss function and the update step is shown below for W1 and similar step is done for all the other parameters (W2, W3, B1, B2, B2).

ΔW1 = ẟH/ẟW1

W1 = W1 - η \* ΔW1

## 3.4 Validation and Testing

We After all the sample in the training dataset have been trained on and the parameters updated, the validation data is tested for accuracy and the next iteration of training is started based on the accuracy. In the next iteration, the training dataset is shuffled around so that each sample has no dependency on its previous or the next sample and is trained as if it is chosen independently. This leads to a faster convergence and is more efficient.

Once the training is completed, we have run the neural network on the test dataset to calculate the accuracy and thus measuring the performance of our digit classifier.

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TABLE 1  
Units for Magnetic Properties



Statements that serve as captions for the entire table do not need footnote letters.

aGaussian units are the same as cgs emu for magnetostatics; Mx = maxwell, G = gauss, Oe = oersted; Wb = weber, V = volt, s = second, T = tesla, m = meter, A = ampere, J = joule, kg = kilogram, H = henry.

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2. Items will be punctuated as sentences where it is appropriate.
3. Items will be numbered, followed by a period.

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Theorems and related structures, such as axioms corollaries, and lemmas, are formatted using a hanging indent paragraph. They begin with a title and are followed by the text, in italics.

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**Acknowledgment**

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**References**

1. Subhransu Maji and Jitendra Malik. “Fast and Accurate Digit Classification.” https://www2.eecs.berkeley.edu/Pubs/TechRpts/2009/EECS-2009-159.pdf
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