Report on CSC7700 Project 1

Multi-Layer Perceptron for Classification and Regression

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ABSTRACT

This study presents the design, implementation, and evaluation of a Multilayer Perceptron (MLP) model applied to two machine learning tasks: handwritten digit classification using the MNIST dataset and vehicle fuel efficiency prediction using the Auto MPG dataset. The MLP model comprises multiple fully connected layers utilizing activation functions such as ReLU and Softmax (for MNIST), and ReLU and Linear (for MPG), trained using backpropagation and optimized with the RMSprop algorithm. For MNIST classification, the model achieves an accuracy of **97.69%** on the test set. For vehicle MPG regression, the model achieves a loss of **6.825 MSE** (Mean Squared Error) on the test set and the R2 score is **0.8619**, indicating a reliable performance in the models.

METHODOLOGY

The methodology involves the implementation of an MLP model, data preprocessing, training, and evaluation for two different machine learning tasks: classification and regression.

1. Model Design:
   For the MNIST classification task, the MLP model consists of five layers:
   - Input layer: 784 neurons (flattened image pixels)
   - Four hidden layers:
     - 256 neurons with ReLU activation.
     - 128 neurons with ReLU activation.
     - 64 neurons with ReLU activation.
     - 32 neurons with ReLU activation.
   - Output layer with 10 neurons (one for each digit class) using Softmax activation.

   For the Auto MPG regression task, the MLP model consists of three layers:

   - Input layer corresponding to the number of features after preprocessing.
   - Two hidden layers with 64 and 32 neurons, respectively, using ReLU activation.
   - Output layer with a single neuron using a Linear activation function for continuous value prediction.

- Dropout regularization is incorporated in both models training with dropout rate as 0.03 to train the MNIST dataset and as 0.07 to train the MPG dataset.
- The loss functions used are Cross Entropy for classification and Mean Squared Error for regression.

2. Data Preparation:

   MNIST Dataset:

   The MNIST dataset is loaded using the *torchvision.datasets.MNIST* module and downloaded if not available locally. Images are loaded as raw byte data, reshaped into a (size, 28, 28) array, and normalized to a [0,1] range. The images are flattened into a vector of 784 features for input into the MLP model. Labels are one-hot encoded to represent each class as a binary vector.

   Auto MPG Dataset:

   The dataset is loaded from the UCI repository. Non-numeric categorical attributes, such as *car_name*, are dropped. Missing values in numerical features, such as *horsepower*, are removed to maintain data integrity. The *origin* column, which represents categorical data, is one-hot encoded for numerical representation. The dataset is split into 70% training, 15% validation, and 15% test sets using *train_test_split*.

3. Training Process:

   The training involves mini-batch gradient descent with the RMSprop optimizer, utilizing a learning rate of 0.0001 for classification and 0.001 for regression. Weights are initialized using Glorot Uniform Initialization and biases as zeros. Batch sizes of 64 samples are used, and training is conducted for 25 epochs for classification and 80 epochs for regression. Forward propagation computes the network's predictions, while backpropagation updates the weights and biases.

4. Training Challenges:

   Initially the model was overfitting to the training data, but gradually it was being handled with hit and trial of different dropout rates. Other challenges include hyperparameters (like learning rate, batch-size, dropout rate and number of epochs) tuning and finding the best fit activation functions. Best results were seen with the application of ReLU activation function to the hidden layers.

RESULTS

MNIST Dataset

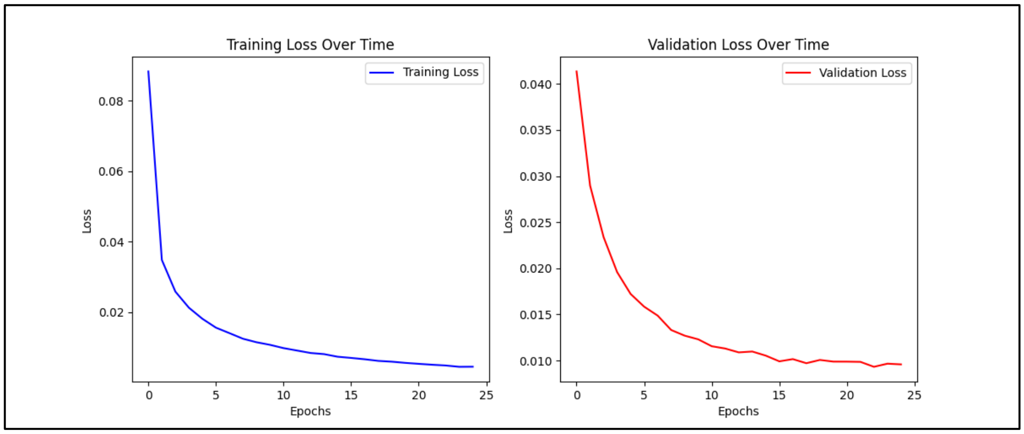

Figure: The Training vs Validation loss for the MNIST dataset.

The model exhibits an overall accuracy of 97.69% on the test data. The images are predicted accurately. The predicted images of numbers are shown below.

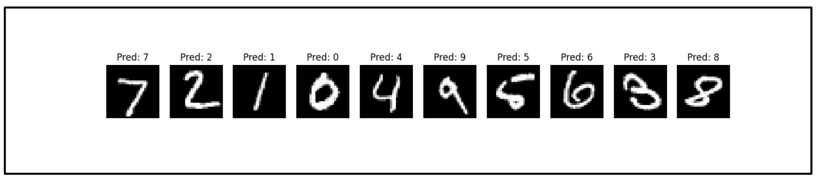

Figure: The prediction of the images by the model.

Classification Report:

	precision	recall	f1-score	support
0	0.98	0.99	0.98	980
1	0.99	0.99	0.99	1135
2	0.96	0.98	0.97	1032
3	0.97	0.98	0.97	1010
4	0.98	0.97	0.98	982
5	0.98	0.97	0.97	892
6	0.98	0.97	0.98	958
7	0.98	0.97	0.98	1028
8	0.97	0.97	0.97	974
9	0.97	0.97	0.97	1009
accuracy			0.98	10000
macro avg	0.98	0.98	0.98	10000
weighted avg	0.98	0.98	0.98	10000

Test Accuracy: 0.9769

Figure: The Confusion matrix for the test MNIST data.

Vehicle MPG Dataset

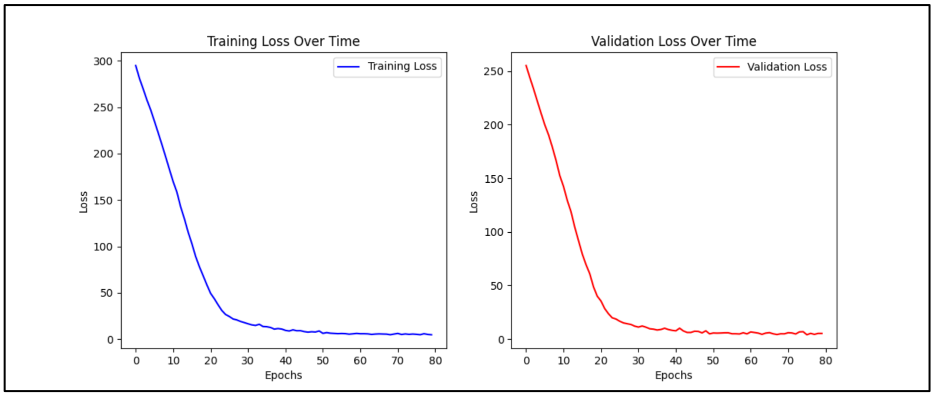

Figure: The Training vs Validation loss for the MPG dataset.

The model achieves a total loss of 6.825 MSE and R2 score of 0.8619 on the test sample. Also, ten different samples have been selected to test the predicted MPG against the actual MPG. The results are shown below in the figure and table.

🔷 Predicted vs True MPG (10 Random Samples)

Index	True MPG	Predicted MPG	Abs Error
51.0	20.00	17.97	2.03
15.0	19.40	20.50	1.10
55.0	26.00	29.72	3.72
54.0	29.80	36.56	6.76
42.0	26.00	31.70	5.70
0.0	20.00	18.67	1.33
48.0	10.00	11.00	1.00
10.0	27.40	27.67	0.27
14.0	36.00	36.10	0.10
7.0	15.00	15.95	0.95

Table: Predicted MPG vs Actual MPG for 10 samples.

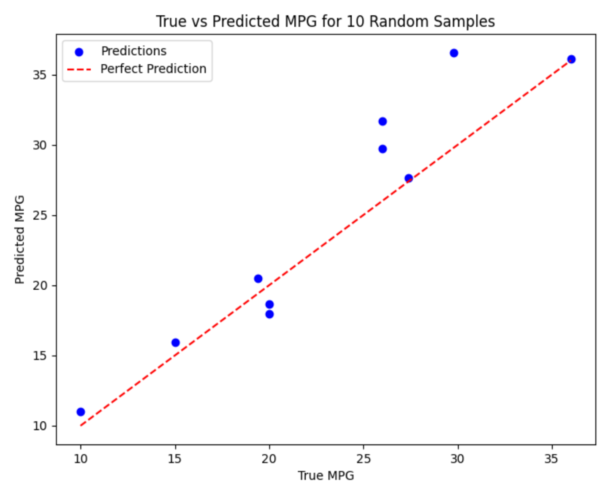

Figure: Predicted vs actual for the 10 samples.

It can be seen the results are quite satisfactory with less Abs Error.

<u>DISCUSSION AND CONCLUSION</u>

The project helped us in understanding the fundamentals of Multi-layer Perceptron and in evaluating MLP for regression and classification applications. Not only did we implement the MLP, but also gained knowledge regarding data preprocessing or data clean-up and, also tuning the hyper-parameters such as learning rate, no. of epochs, dropout rate, etc., to gain the best results. As already seen above, the results exhibited by the MLP models are as expected.