Comparative Analysis of Fully Connected ANN and CNN for MNIST Classification

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1 Introduction

The purpose of this report is to compare the performance of a Fully Connected Artificial Neural Network (FC-ANN) and a Convolutional Neural Network (CNN) on the MNIST digit classification task. The models are evaluated based on their architecture, number of parameters, and overall accuracy.

2 Methodology

Both models were implemented using TensorFlow and trained on the MNIST dataset, which consists of 60,000 training images and 10,000 test images of handwritten digits (0-9). The dataset was normalized to the range [0,1] by dividing pixel values by 255. The training process included the following steps:

- Data preprocessing: Normalization and reshaping.
- Model training: Using Adam optimizer with categorical cross-entropy loss.
- Evaluation: Test accuracy and loss were recorded after training.

3 Model Architectures

3.1 Fully Connected ANN

The architecture of the FC-ANN is as follows:

- Input Layer: 784 neurons (flattened 28x28 images)
- Dense Layer (512 neurons, ReLU)
- Dropout (20%)
- Dense Layer (512 neurons, ReLU)
- Dropout (20%)
- Output Layer: 10 neurons (Softmax activation)

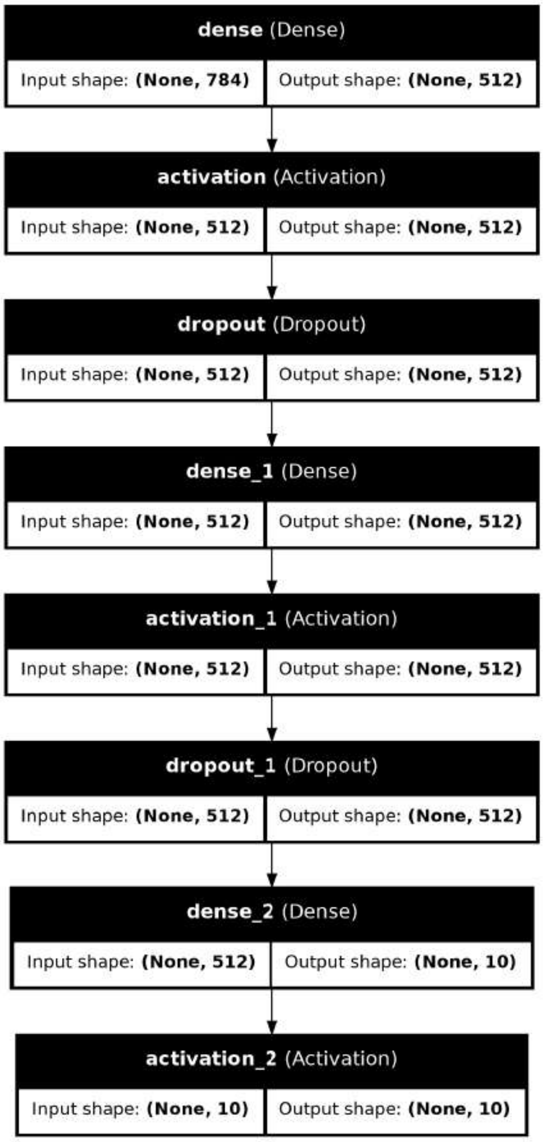

Figure 1: Architecture of Fully Connected ANN

3.2 Convolutional Neural Network

The architecture of the CNN is as follows:

- Convolutional Layer (32 filters, 3x3 kernel, ReLU)
- MaxPooling (2x2)
- Convolutional Layer (64 filters, 3x3 kernel, ReLU)
- MaxPooling (2x2)
- Flatten Layer
- Dense Layer (128 neurons, ReLU)
- Dropout (20%)
- Dense Layer (64 neurons, ReLU)

- Dropout (20%)
- Output Layer: 10 neurons (Softmax activation)

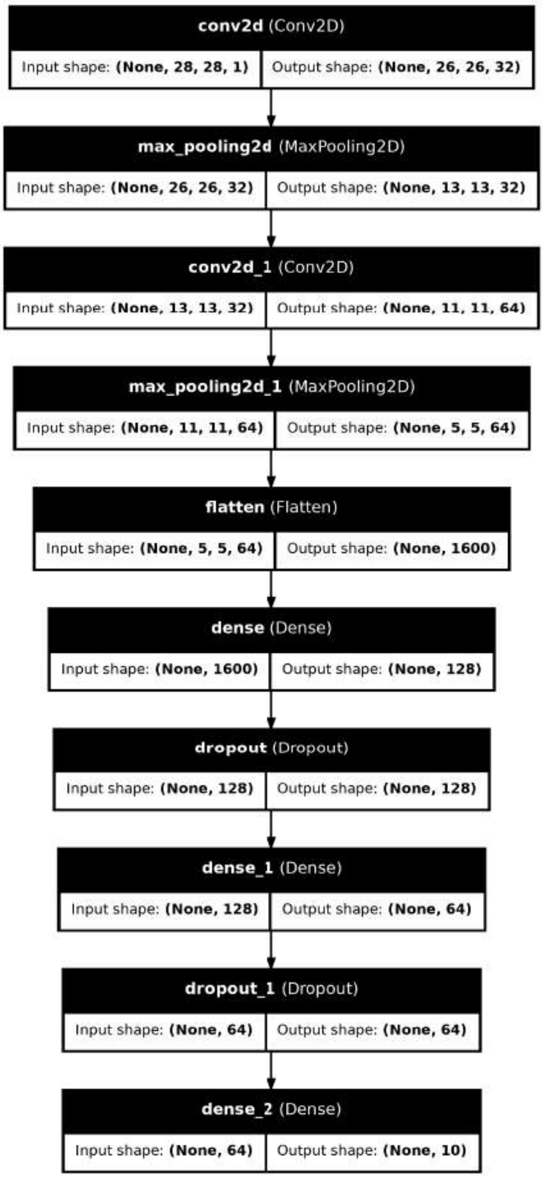

Figure 2: Architecture of Convolutional Neural Network

4 Model Comparison

4.1 Parameter Counts

Table 1 compares the number of trainable parameters in both models.

4.2 Performance Metrics

Both models were trained on the MNIST dataset, and their accuracy was measured on the test set. CNNs typically outperform fully connected networks due to their ability to capture spatial features. Table 2 summarizes the accuracy of each model.

Model	Total Parameters
Fully Connected ANN	669,706
CNN	232,650

Table 1: Comparison of model parameters.

Model	Test Accuracy
Fully Connected ANN	98.4%
CNN	99.1%

Table 2: Comparison of test accuracy.

4.3 Training Time and Efficiency

The CNN model, despite having fewer parameters, took longer to train per epoch due to the convolutional operations. However, it achieved higher accuracy with fewer parameters, demonstrating better efficiency in extracting features from images.

4.4 Why Fully Connected ANN is More Expensive

The Fully Connected ANN is computationally more expensive than the CNN due to the following reasons:

- **More Parameters:** The ANN has 669,706 parameters compared to 232,650 in the CNN. Fully connected layers require every neuron to connect to every other neuron, leading to a large number of parameters.
- **Higher Memory and Computation Cost:** Due to a large number of parameters, ANNs require more memory and computation during both forward and backward propagation.
- **Feature Extraction Efficiency:** CNNs extract meaningful features like edges, shapes, and textures, reducing the burden on the fully connected layers, making them more efficient for image-related tasks.

5 Conclusion

The CNN model achieves better performance with fewer parameters than the fully connected ANN. This is due to the ability of convolutional layers to extract hierarchical spatial features, making CNNs more efficient for image classification tasks. The FC-ANN, although achieving reasonable accuracy, has significantly more parameters, making it computationally more expensive.

Future work can involve experimenting with deeper architectures, using techniques such as data augmentation, or fine-tuning hyperparameters to further improve accuracy.