# Project Synopsis

## Title

Design and Implementation of a Neural Network Classifier Using First-Principles Engineering Methods

## Abstract

This project demonstrates the design, implementation, and evaluation of a neural network classifier developed entirely from first principles using the Python programming language. The objective of the work is to demonstrate engineering competency in algorithm design, numerical analysis, and performance evaluation by implementing all major components of a neural network without relying on machine learning frameworks.

The implemented solution includes explicit design and implementation of weight initialization, forward propagation, activation functions, loss computation, backward propagation, and gradient-based optimization. The neural network was evaluated using the Fashion-MNIST dataset, a standard benchmark dataset for image classification. Model performance was assessed using prediction accuracy and mean squared error over multiple training epochs to examine convergence behaviour and learning stability.

The project demonstrates that a manually engineered neural network can successfully learn meaningful data representations, as evidenced by increasing accuracy and decreasing error during training. The proof of concept confirms the validity of the design while also identifying limitations and opportunities for improvement for practical engineering applications.

## Project Objectives

The primary objectives of this project are to:

1. Design a neural network classifier based on established machine learning theory.
2. Implement all learning components explicitly in Python without using pre-built machine learning models.
3. Justify design decisions related to activation functions, optimization methods, and performance metrics.
4. Analyze the convergence behaviour and performance of the model during training.
5. Evaluate whether the implementation satisfies defined acceptance criteria for a proof of concept.
6. Identify limitations and recommend improvements for real-world deployment.

## Approach and Methods

The project follows an engineering design approach grounded in theoretical principles of neural networks. The model architecture consists of a single-layer neural network that processes flattened image inputs and produces class predictions.

The methodology includes:

- Data preprocessing and normalization of input features
- Xavier-based weight initialization to stabilize gradient propagation
- Sigmoid activation for neuron outputs
- Mean squared error as the loss function
- Manual derivation and implementation of gradients using the chain rule
- Mini-batch gradient descent for iterative parameter optimization

The implementation was designed to prioritize transparency of calculations and traceability between mathematical theory and executable code.

## Performance Evaluation

Model performance was evaluated using:

- Classification accuracy to measure predictive correctness
- Mean squared error to quantify prediction error
- Accuracy and error trends across successive training epochs

Acceptance criteria were defined to verify proof of concept, including consistent improvement in accuracy, decreasing error values, and performance exceeding random classification.

## Expected Results and Conclusions

The expected outcome of the project was a demonstrable improvement in model accuracy accompanied by decreasing error as training progressed. The project was also expected to highlight the strengths and limitations of a single-layer neural network implemented from first principles.

The conclusions of the project focus on validating the engineering design, assessing the effectiveness of chosen methods, and identifying practical enhancements such as improved activation functions, alternative loss metrics, and deeper network architectures.

## Practical Applications and Recommendations

The proof of concept may be adapted for practical applications by extending the architecture to multi-layer networks, adopting more appropriate optimization techniques, and improving computational efficiency. The project provides a foundational framework suitable for further engineering development and deployment.