Assignment 1 (Weeks 2–3)

Foundations of Neural Networks and Backpropagation

Lectures Covered Summary (Weeks 2–3)

- Machine Learning Basics – Supervised Learning, Loss Functions, Perceptron
- Feedforward Neural Networks (MLP) and Backpropagation Concept
- Deep Neural Network Concepts and Backpropagation Implementation

Dataset: California Housing Prices Dataset

- **Source:** 1990 U.S. Census
- **Distributed by:** scikit-learn
- **Task:** Supervised regression

  Access method (required):

```
from sklearn.datasets import fetch_california_housing
data = fetch_california_housing(as_frame=True)
```

Assignment Objective

The objective of this assignment is to develop a rigorous understanding of feedforward neural networks and backpropagation through hands-on implementation and analysis. Students will examine how loss functions, gradient descent, and network depth influence learning behavior in multi-layer perceptrons.

Questions

Q1. Supervised learning formulation
Formulate the regression problem using the California Housing dataset. Clearly specify the input variables, output variable, and learning objective. Explain why this task falls under supervised learning and why a feedforward neural network is an appropriate modeling choice.

Q2. Loss functions and learning dynamics
Train the same MLP architecture using Mean Squared Error (MSE) and Mean Absolute Error (MAE) loss functions. Compare their convergence behavior and final validation performance. Discuss how each loss function influences gradient descent and optimization dynamics.

Q3. Perceptron and representational capacity

Implement a single-layer neural network (perceptron-style, no hidden layers) and a multi-layer perceptron with at least two hidden layers. Compare their predictive performance and explain the representational limitations of the single-layer model.

Q4. Backpropagation and gradient propagation

Analyze the backpropagation process by tracking gradient norms for each layer during training. Demonstrate that gradients propagate through the network and discuss any observed stability or instability in gradient flow.

Q5. Effect of network depth

Train MLPs with varying depths (e.g., one, three, and five hidden layers). Compare convergence speed, training stability, and generalization performance. Discuss how increasing depth impacts optimization.

Q6. Model selection and synthesis

Select the best-performing network configuration. Justify your selection using evidence from loss curves, gradient behavior, and validation results. Briefly reflect on one limitation of feedforward neural networks highlighted by this assignment.

Deliverables

You must submit the following items via Canvas (share a GitHub link):

- **Jupyter Notebook (.ipynb):** Well-documented, executable end-to-end, including code, outputs, and plots.