Assignment: Non-Deterministic Unsupervised Neural Network Model

Neural Networks Course
Due: $14^{th} September, 2025$

Objective

Design and implement a non-deterministic unsupervised neural network model for one of the following applications: data generation, clustering, or dimensionality reduction. Evaluate your model using appropriate metrics and prepare a comprehensive report documenting your approach, results, and analysis.

1 Problem Statement

Unsupervised learning deals with extracting patterns from unlabeled data. Non-deterministic models introduce stochasticity, enabling better exploration of the data space and uncertainty quantification. In this assignment, you will:

1. Select an unsupervised learning task (generation, clustering, etc.)
2. Design a non-deterministic neural network architecture
3. Implement and train the model
4. Evaluate using appropriate metrics
5. Analyze the results and model behavior

2 Model Architecture Options

Select one of the following architectures to compare with your propose one:

2.1 Variational Autoencoder (VAE) for Generation

$$\mathcal{L} = \mathbb{E}_{q(z|x)}[\log p(x|z)] - \beta D_{KL}(q(z|x) \| p(z)) \tag{1}$$

2.2 Bayesian Deep Clustering Network

$$p(\theta|D) = \frac{p(D|\theta)p(\theta)}{p(D)} \tag{2}$$

2.3 Stochastic Embedding Network

$$z = f(x) + \epsilon \quad \text{where} \quad \epsilon \sim \mathcal{N}(0, \sigma^2) \tag{3}$$

3 Evaluation Criteria

3.1 For Generative Models

- **Fréchet Inception Distance (FID)**: Lower values indicate better quality
- **Inception Score (IS)**: Higher values indicate better diversity and quality
- **Reconstruction Error**: MSE between original and reconstructed samples
- **Visual Quality**: Subjective assessment of generated samples

3.2 For Clustering Models

- **Silhouette Score**: Measures separation between clusters (-1 to 1)
- **Adjusted Rand Index (ARI)**: Similarity between true and predicted clusters (0 to 1)
- **Normalized Mutual Information (NMI)**: Information-theoretic measure (0 to 1)
- **Stability**: Consistency across different random initializations

3.3 For Dimensionality Reduction

- **Reconstruction Error**: Ability to preserve information
- **Trustworthiness**: Preservation of local neighborhoods
- **Continuity**: Preservation of global structure
- **Dimensionality Quality**: Variance explained per dimension

4 Sample Pseudocode

Algorithm 1 Non-Deterministic Unsupervised Learning Framework

```
procedure Main
    Load and preprocess dataset X
    Initialize model parameters θ
    Define loss function ℒ
    Set hyperparameters: learning rate η, epochs T
    for t ← 1 to T do
        Sample mini-batch ℬ ∼ X
        Sample noise ϵ ∼ p(ϵ)
        Compute stochastic representation z = f_θ(ℬ, ϵ)
        Compute reconstruction x̂ = g_θ(z)
        Compute loss ℒ = reconstruction + β · regularization
        Update parameters: θ ← θ − η∇_θ ℒ
    end for
    Evaluate model on test set
    Analyze results and uncertainty
end procedure
```

5 Implementation Guidelines

5.1 Required Components

- Stochastic sampling mechanism (reparameterization trick)
- Appropriate regularization for the chosen architecture
- Multiple evaluation metrics from relevant categories

- Uncertainty quantification methods
- Comparative analysis with deterministic baseline

5.2 Technical Requirements

- Implement in PyTorch/TensorFlow
- Use appropriate initialization schemes
- Include proper data preprocessing
- Implement early stopping if necessary
- Provide visualization of results

6 Report Structure

Your report should include the following sections:

6.1 Introduction

- Problem motivation and background
- Choice of application and justification
- Research questions or objectives

6.2 Related Work

- Brief survey of existing approaches
- Limitations of current methods
- Novelty of your approach

6.3 Methodology

- Detailed model architecture
- Mathematical formulation
- Training procedure and hyperparameters
- Evaluation metrics with justifications

6.4 Experimental Setup

- Dataset description and preprocessing
- Implementation details
- Hardware/software environment
- Baseline methods for comparison

6.5 Results and Analysis

- Quantitative results (tables and figures)
- Qualitative analysis (visualizations)
- Statistical significance testing
- Uncertainty analysis
- Failure cases and limitations

6.6 Discussion

- Interpretation of results
- Comparison with existing methods
- Insights gained from non-deterministic approach
- Theoretical implications

6.7 Conclusion

- Summary of contributions
- Future work directions
- Practical applications and implications

Criterion	Description	Weight
Theoretical Understanding	Depth of mathematical formulation	20%
Implementation Quality	Code organization, efficiency, documentation	25%
Experimental Design	Appropriate metrics, baselines, comparisons	20%
Analysis and Interpretation	Insightful discussion of results	20%
Report Quality	Organization, clarity, presentation	15%

Table 1: Assignment grading criteria

7 Grading Rubric

Submission Guidelines

- Submit your report as a PDF document
- Include all source code as a separate zip file
- Provide instructions for running your code
- Include any additional resources needed to reproduce results

References

[1] Kingma, D. P., & Welling, M. (2013). Auto-Encoding Variational Bayes. arXiv preprint arXiv:1312.6114.

[2] Higgins, I., et al. (2016). Beta-VAE: Learning Basic Visual Concepts with a Constrained Variational Framework.

[3] Xie, J., Girshick, R., & Farhadi, A. (2016). Unsupervised deep embedding for clustering analysis.