Bridging Deep Learning and Statistical Dimension Reduction: An SNN–PCA Framework for Efficient Learning

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Abstract

Deep learning models offer strong predictive capability but are often criticized for high computational cost and limited interpretability, particularly in data analysis. This study introduces a statistically grounded framework that integrates Siamese Neural Networks (SNNs) with Principal Component Analysis (PCA) to enhance representation learning and model efficiency. The SNN is employed as a nonlinear feature extractor that maps high-dimensional inputs into a latent space with improved class separability. These learned representations are then incorporated into classical statistical learning models to strengthen anomaly detection and classification performance. PCA is further applied to SNN-derived features and network weight structures to quantify contribution, reduce dimensionality, and prune redundant neurons. Empirical studies demonstrate that the SNN–PCA framework improves F1-score and balanced accuracy while substantially reducing network complexity. This work illustrates how statistical dimension reduction can be synergistically combined with deep learning to deliver interpretable, computationally efficient, and high-performing models for structured data applications.

Keyword: Siamese Neural Networks (SNN), Principal Component Analysis (PCA), Dimensionality Reduction, Classification, Network Pruning