# ML Pipeline for Multiclass MNIST Classification

*Programmatic Optimization, Hyperparameter Tuning, and Advanced Ensemble Architecture*

Raghav Iyengar

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## Abstract

This report is about implementation of a machine learning pipeline using NumPy and SciPy, aiming to do Multiclass classification of MNIST dataset. XGBoostClassifier was tried as an option but it was observed that it did not give enough accuracy for the amount of time taken by the model. Simpler models like KNN and Softmax were giving good accuracy without less computation. The final solution is a stacked model `KFoldStackingEnsemble` that tries to do the classification faster by dimensionality reduction through PCA and LDA. This architecture, built using (`NumPyKNNClassifier` and `SoftmaxClassifier`), acheived a good validation accuracy showing that combining simple models and techniques can give good accuracy.

## Contents

# 1 Summary of Models Used & System Architecture

## 1.1 Models Implemented

Three models were built using Numpy and Scipy:

1. **SoftmaxClassifier (Linear Model):** Model made for multiclass logistic regression where the softmax funxtion is used for probability. Optimized using stochastic mini-batch gradient descent and numerical stability accounted for. This model was used because of its good accuracy.

2. **NumPyKNNClassifier (Distance-Based Model):** A k-Nearest Neighbors classifier. Numpy vector operations were used to make the distance matrix computation faster.

3. **XGBoostClassifier (Tree Ensemble):** A gradient boosting implementation which was extended from the previous assignment. This did not give any sufficient accuracy increase for the amount of training time so it was excluded.

## 1.2 Pre-Processing Pipeline

To make the models better and lesser time taking, the following pre processing techniques were used:

1. **NumPyScaler:** This works similar to the StandardScaler making each column standard variance 1 and mean centered.

2. **PCA:**To find the dimensions capturing most of the variance, PCA was performed on the Scaled dataset and different number of directions were used based on the required optimizations.

3. **LDA:** LDA was performed on the data to find the vetor directions which maximize the class separability. This redices the dimensions to 9.

This was done to prevent the complexity of high dimensions while using a model like KNN because the predict time will be very high.

## 1.3 Final System Architecture: K-Fold Stacking Ensemble

Instead of using parameterized weighted averages, cross validation predictions were used as robust predictions and then ensembled.



**Architecture Diagram**
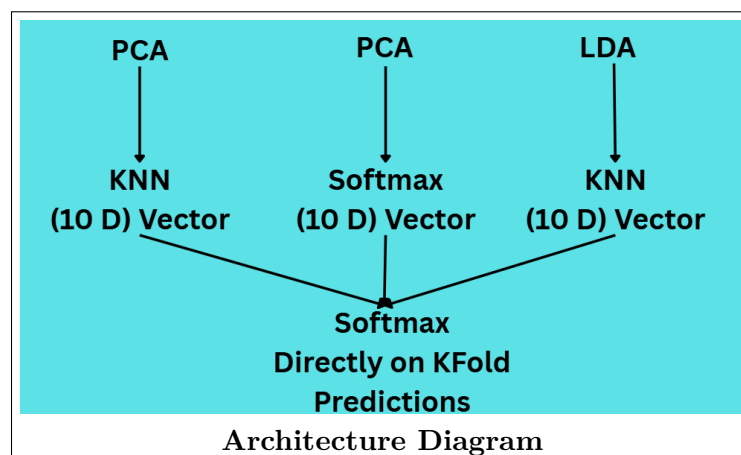
- **Level 0 (Base Learners):** Three models were used to generate cross-validated features for the final model.

    - `NumPyKNNClassifier` (on 50 PCA features)
    - `SoftmaxClassifier` (on 175 PCA features)
    - `NumPyKNNClassifier` (on 9 LDA features)

- **Meta-Feature Generation:** 3 Fold cross-validation was used to generate the features. 2/3rd of the dataset was used to makee predictions about one third of the dataset using all the three models. This was done to prevent overfitting on the training dataset.

- **Level 1 (Meta-Model):** A final `SoftmaxClassifier` was trained on the model to generate the predicted class

# 2  Summary of Hyper-parameter Tuning

## 2.1  NumPyKNNClassifier Tuning

Models with different number of components and K were run giving the results below
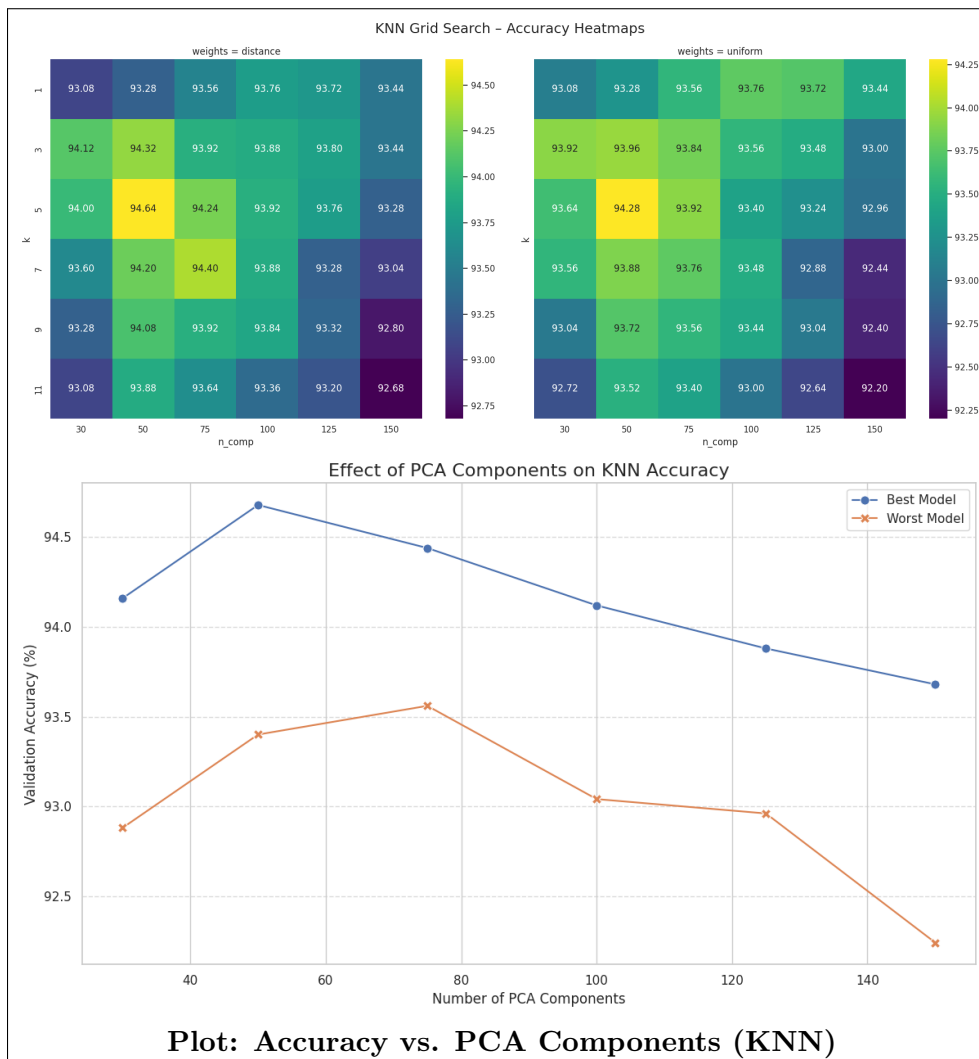


Figure 1: Performance peaked at 50 PCA components and dropped on either side.
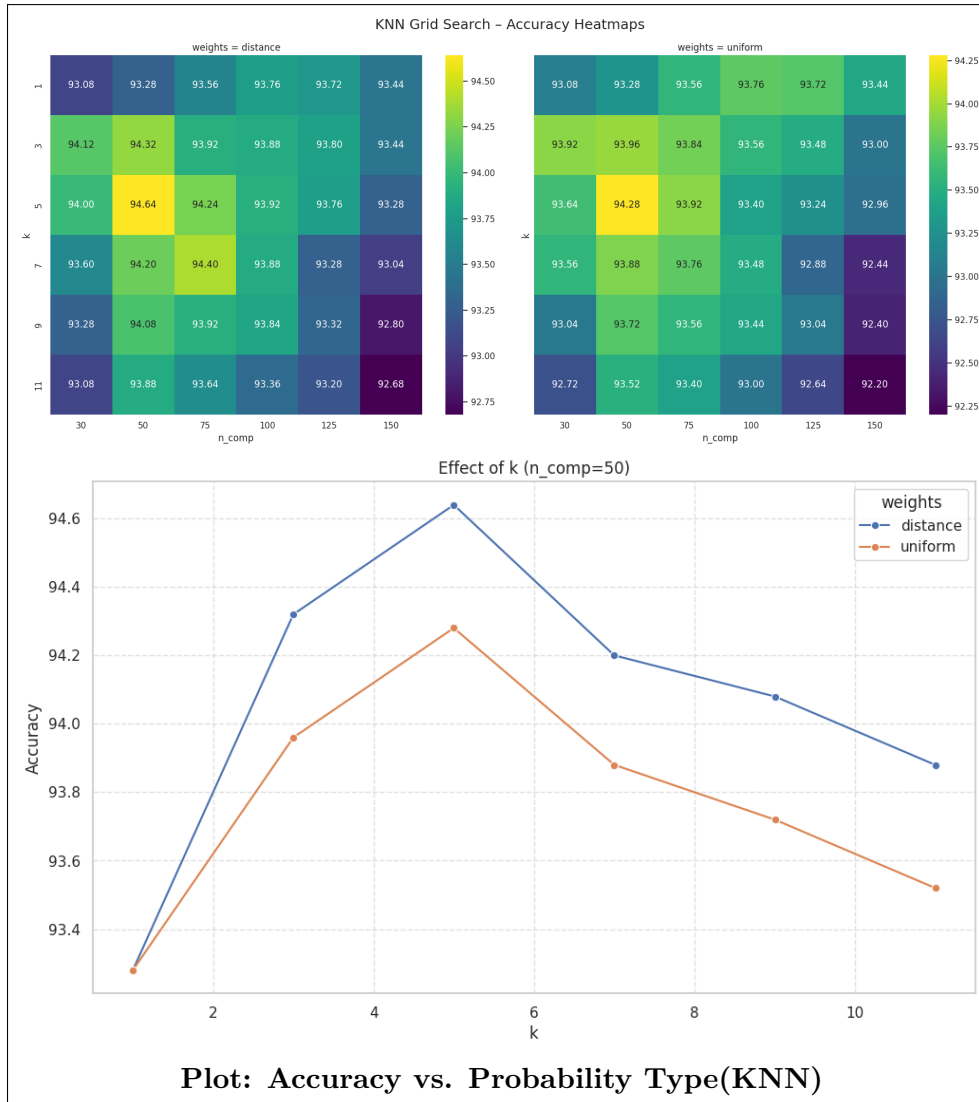
Figure 2: Distance proportional probabilistic choices work better.

- **Key Finding 1:** Taking around 50 components allowed the models to balance both the requirements of taking the variance into account as well as keeping noise in check.

- **Key Finding 2:** Giving probability proportional to distance choices works better than the equal probability.

- **Key Finding 3:** Low k values like 3-5 were performing well.

- **Best Model:** `PCA(n=50) + KNN(k=5, weights='distance')`.

## 2.2 SoftmaxClassifier Tuning



**Plot: Accuracy vs. Parameters (Softmax)**
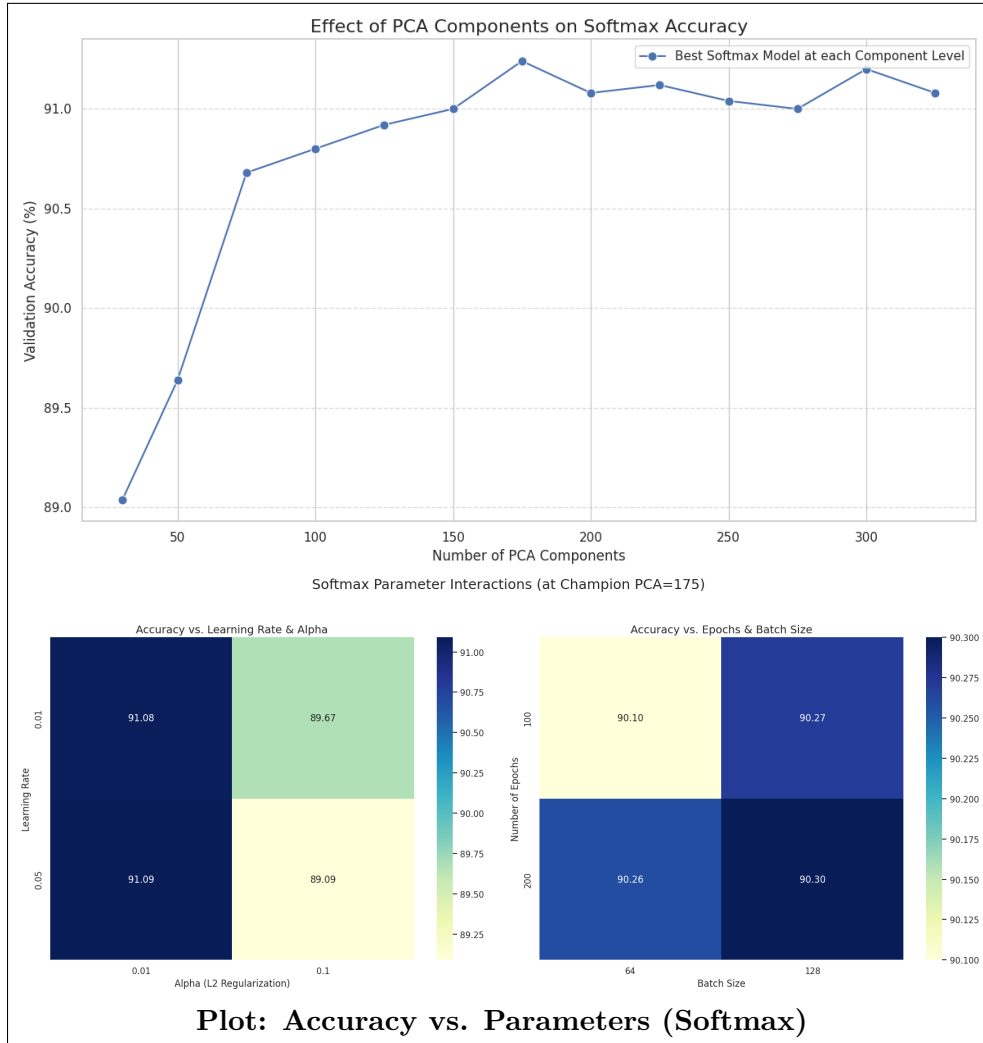
Figure 3: The linear Softmax model's accuracy improved as more PCA components were added.

- **Key Finding 1:** The linear Softmax model was more robust to noise as its accuracy consistently improved as more PCA components were added from below 89 percent with 30 components to just less than 91.25 percent with 175 components. After 175, there isnt much gain so we can stop there.

- **Key Finding 2:** The learning rate and regularization optimal quantities are inversely proportional.

- **Best Model:** `PCA(n=175) + Softmax(epochs=100, lr=0.05, alpha=0.01, batch=128)`.

## 2.3 Analysis of Model Performance on LDA Features



Figure 4: KNN Performance on Left/Softmax Performance on Right

- **KNN on LDA (Left Plot):** The 9 dimensional LDA is sparser, that is why we need 11-13 neighbors to give the best results. Again, distance proportionality makes gives higher accuracy.

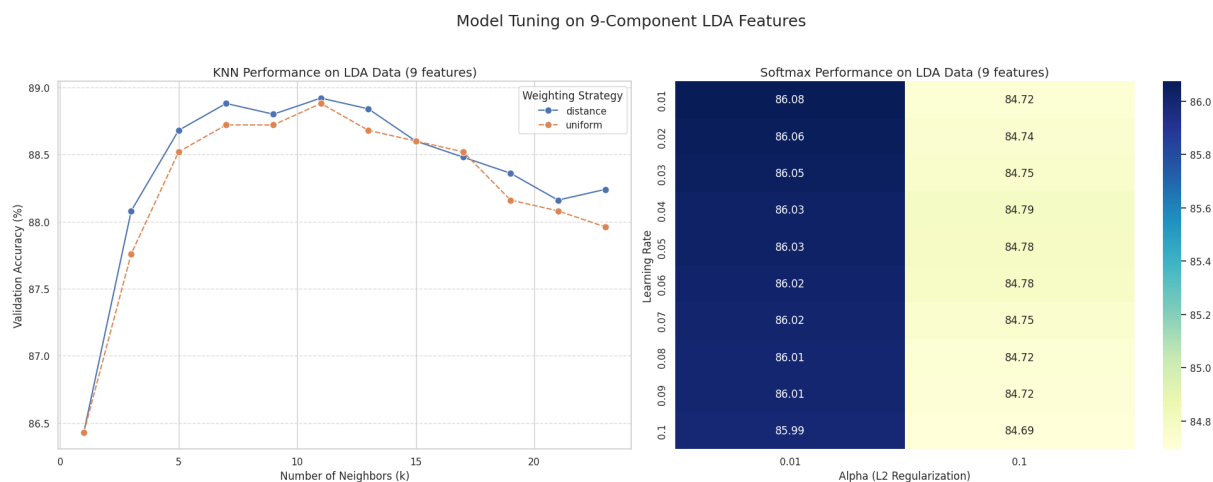- **Softmax on LDA (Right Plot):** The softmax classifier performed decently well on this dataset, but gave slightly lower accuracy. Here low regularization and learning rate gave best accuracy and the vice versa gave the worst.

# 3 Detailed Summary of Thoughts and Observations

The 5-minute (300s) runtime constraint invalidated the `XGBoostClassifier` because it achieved low accuracy when this training time was taken into consideration inspite of being a complex model.

Hence, for faster training, we have to make an ensemble of simpler models to get a higher accuracy.

We used KNN Classifier and Softmax Classifier for this. The main tuning was to find the optimal parameters for this accounting for accuracy and overfitting.

## 3.1 Algorithm NumPyKNNClassifier:- Inherently low bias,high variance

- **Things to keep in mind:** Non linear model.When we use high k, KNN becomes a low variance,high bias model but when we use low k, the KNN becomes a low bias,high variance model.

- **Hyperparameter Tuning & Bias-Variance Evaluation:**

  - **k (n_neighbors):** The primary knob for controlling variance.
    * Low $k$ ($k = 1$) → high variance, low bias. High accuracy.
    * High $k$ (e.g., $k = 23$) → high bias, low variance. Accuracy dropped.
    * **Optimal range:** $k \in [3, 7]$ which lies between these two.
  - **weights:**
    * **uniform**: higher bias, lower variance.
    * **distance**: lower bias, higher variance.

&ast; **Result:** `distance` $>$ `uniform`.

> **Optimal Parameters -** $\text{PCA}(n = 50) + \text{KNN}(k = 5, \text{weights} = \text{distance})$

## 3.2 Algorithm SoftmaxClassifier:- Inherently high bias,low variance

- **Things to keep in mind:** Linear model

- **Hyperparameter Tuning & Bias-Variance Evaluation:**

  - `alpha` **(L2 regularization):**
    * High $\alpha$ (0.1) $\rightarrow$ increased bias $\rightarrow$ accuracy drops
    * Low $\alpha$ (0.01) $\rightarrow$ decreased bias $\rightarrow$ best performance
  - `n_epochs`, `lr`, `batch_size`: These are for the optimization of the model. Could be used in the best possible state beacuse the running doesnt take very long.

  > **Optimal Parameters -** $\text{PCA}(n = 175) + \text{Softmax}(100, 0.05, 0.01, 128)$

## 3.3 Algorithms for Dimensionality Reduction

- **PCA (Variance-Driven):**

  - Low components (30) $\rightarrow$ high bias, low variance. Good for KNN, bad for Softmax.
  - High components (150) $\rightarrow$ low bias, high variance. Good for Softmax, bad for KNN.

- **LDA (Class-Separation-Driven):**

  - High-bias: compresses $784 \rightarrow 9$ features.
  - Best results: KNN $>$ Softmax.

## 3.4 Final Observation: Optimal Ensemble

The final ensemble combines complementary models:

1. High-variance model: $\text{PCA}(50) + \text{KNN}$

2. High-bias model: $\text{PCA}(275) + \text{Softmax}$

3. Specialists: $\text{LDA}(9) + \text{KNN}$

4. Stacking with KFold to reduce overfitting

This ensemble achieved **93.64%** accuracy and **93.55%** macro f1-score.

# Appendix: Full Hyperparameter Tunings Results

Table 1: PCA+KNN Hyperparameter Results

| n_comp | k | weights | Accuracy | F1-Score | Fit (s) |
|---|---|---|---|---|---|
| 50.000000 | 5.000000 | distance | 94.640000 | 94.590000 | 0.000000 |
| 75.000000 | 7.000000 | distance | 94.400000 | 94.350000 | 0.000000 |
| 50.000000 | 3.000000 | distance | 94.320000 | 94.250000 | 0.000000 |
| 50.000000 | 5.000000 | uniform | 94.280000 | 94.220000 | 0.000000 |
| 75.000000 | 5.000000 | distance | 94.240000 | 94.200000 | 0.000000 |
| 50.000000 | 7.000000 | distance | 94.200000 | 94.150000 | 0.000000 |
| 30.000000 | 3.000000 | distance | 94.120000 | 94.040000 | 0.000000 |
| 50.000000 | 9.000000 | distance | 94.080000 | 94.040000 | 0.000000 |
| 30.000000 | 5.000000 | distance | 94.000000 | 93.940000 | 0.000000 |
| 50.000000 | 3.000000 | uniform | 93.960000 | 93.880000 | 0.000000 |
| 30.000000 | 3.000000 | uniform | 93.920000 | 93.840000 | 0.000000 |
| 75.000000 | 3.000000 | distance | 93.920000 | 93.860000 | 0.000000 |
| 75.000000 | 5.000000 | uniform | 93.920000 | 93.880000 | 0.000000 |
| 75.000000 | 9.000000 | distance | 93.920000 | 93.870000 | 0.000000 |
| 100.000000 | 5.000000 | distance | 93.920000 | 93.870000 | 0.000000 |
| 50.000000 | 7.000000 | uniform | 93.880000 | 93.830000 | 0.000000 |
| 50.000000 | 11.000000 | distance | 93.880000 | 93.830000 | 0.000000 |
| 100.000000 | 3.000000 | distance | 93.880000 | 93.820000 | 0.000000 |
| 100.000000 | 7.000000 | distance | 93.880000 | 93.830000 | 0.000000 |
| 75.000000 | 3.000000 | uniform | 93.840000 | 93.780000 | 0.000000 |
| 100.000000 | 9.000000 | distance | 93.840000 | 93.780000 | 0.000000 |
| 125.000000 | 3.000000 | distance | 93.800000 | 93.740000 | 0.000000 |
| 75.000000 | 7.000000 | uniform | 93.760000 | 93.690000 | 0.000000 |
| 100.000000 | 1.000000 | uniform | 93.760000 | 93.700000 | 0.000000 |
| 100.000000 | 1.000000 | distance | 93.760000 | 93.700000 | 0.000000 |
| 125.000000 | 5.000000 | distance | 93.760000 | 93.710000 | 0.000000 |
| 50.000000 | 9.000000 | uniform | 93.720000 | 93.670000 | 0.000000 |
| 125.000000 | 1.000000 | uniform | 93.720000 | 93.660000 | 0.000000 |
| 125.000000 | 1.000000 | distance | 93.720000 | 93.660000 | 0.000000 |
| 30.000000 | 5.000000 | uniform | 93.640000 | 93.570000 | 0.000000 |
| 75.000000 | 11.000000 | distance | 93.640000 | 93.580000 | 0.000000 |
| 30.000000 | 7.000000 | distance | 93.600000 | 93.550000 | 0.000000 |
| 30.000000 | 7.000000 | uniform | 93.560000 | 93.500000 | 0.000000 |
| 75.000000 | 1.000000 | uniform | 93.560000 | 93.500000 | 0.000000 |
| 75.000000 | 1.000000 | distance | 93.560000 | 93.500000 | 0.000000 |
| 75.000000 | 9.000000 | uniform | 93.560000 | 93.500000 | 0.000000 |
| 100.000000 | 3.000000 | uniform | 93.560000 | 93.510000 | 0.000000 |
| 50.000000 | 11.000000 | uniform | 93.520000 | 93.470000 | 0.000000 |
| 100.000000 | 7.000000 | uniform | 93.480000 | 93.420000 | 0.000000 |
| 125.000000 | 3.000000 | uniform | 93.480000 | 93.420000 | 0.000000 |
| 100.000000 | 9.000000 | uniform | 93.440000 | 93.380000 | 0.000000 |
| 150.000000 | 1.000000 | uniform | 93.440000 | 93.370000 | 0.000000 |
| 150.000000 | 1.000000 | distance | 93.440000 | 93.370000 | 0.000000 |

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| n_comp | k | weights | Accuracy | F1-Score | Fit (s) |
|---|---|---|---|---|---|
| 150.000000 | 3.000000 | distance | 93.440000 | 93.370000 | 0.000000 |
| 75.000000 | 11.000000 | uniform | 93.400000 | 93.340000 | 0.000000 |
| 100.000000 | 5.000000 | uniform | 93.400000 | 93.330000 | 0.000000 |
| 100.000000 | 11.000000 | distance | 93.360000 | 93.310000 | 0.000000 |
| 125.000000 | 9.000000 | distance | 93.320000 | 93.260000 | 0.000000 |
| 30.000000 | 9.000000 | distance | 93.280000 | 93.220000 | 0.000000 |
| 50.000000 | 1.000000 | uniform | 93.280000 | 93.210000 | 0.000000 |
| 50.000000 | 1.000000 | distance | 93.280000 | 93.210000 | 0.000000 |
| 125.000000 | 7.000000 | distance | 93.280000 | 93.220000 | 0.000000 |
| 150.000000 | 5.000000 | distance | 93.280000 | 93.230000 | 0.000000 |
| 125.000000 | 5.000000 | uniform | 93.240000 | 93.180000 | 0.000000 |
| 125.000000 | 11.000000 | distance | 93.200000 | 93.150000 | 0.000000 |
| 30.000000 | 1.000000 | uniform | 93.080000 | 93.010000 | 0.000000 |
| 30.000000 | 1.000000 | distance | 93.080000 | 93.010000 | 0.000000 |
| 30.000000 | 11.000000 | distance | 93.080000 | 93.020000 | 0.000000 |
| 30.000000 | 9.000000 | uniform | 93.040000 | 92.970000 | 0.000000 |
| 125.000000 | 9.000000 | uniform | 93.040000 | 92.980000 | 0.000000 |
| 150.000000 | 7.000000 | distance | 93.040000 | 92.970000 | 0.000000 |
| 100.000000 | 11.000000 | uniform | 93.000000 | 92.920000 | 0.000000 |
| 150.000000 | 3.000000 | uniform | 93.000000 | 92.930000 | 0.000000 |
| 150.000000 | 5.000000 | uniform | 92.960000 | 92.900000 | 0.000000 |
| 125.000000 | 7.000000 | uniform | 92.880000 | 92.810000 | 0.000000 |
| 150.000000 | 9.000000 | distance | 92.800000 | 92.730000 | 0.000000 |
| 30.000000 | 11.000000 | uniform | 92.720000 | 92.650000 | 0.000000 |
| 150.000000 | 11.000000 | distance | 92.680000 | 92.620000 | 0.000000 |
| 125.000000 | 11.000000 | uniform | 92.640000 | 92.560000 | 0.000000 |
| 150.000000 | 7.000000 | uniform | 92.440000 | 92.350000 | 0.000000 |
| 150.000000 | 9.000000 | uniform | 92.400000 | 92.310000 | 0.000000 |
| 150.000000 | 11.000000 | uniform | 92.200000 | 92.120000 | 0.000000 |

Table 2: PCA+Softmax Hyperparameter Results

| Model Configuration (PCA, ep, lr, a, b) | Accuracy | F1-Score | Fit (s) |
|---|---|---|---|
| PCA=175, Softmax (ep=100, lr=0.05, a=0.01, b=128) | 91.240000 | 91.130000 | 3.510000 |
| PCA=300, Softmax (ep=100, lr=0.05, a=0.01, b=64) | 91.200000 | 91.090000 | 6.440000 |
| PCA=175, Softmax (ep=100, lr=0.01, a=0.01, b=64) | 91.160000 | 91.040000 | 3.850000 |
| PCA=300, Softmax (ep=100, lr=0.05, a=0.01, b=128) | 91.160000 | 91.050000 | 5.700000 |
| PCA=175, Softmax (ep=200, lr=0.01, a=0.01, b=128) | 91.120000 | 91.000000 | 7.470000 |
| PCA=225, Softmax (ep=100, lr=0.05, a=0.01, b=64) | 91.120000 | 90.990000 | 5.510000 |
| PCA=175, Softmax (ep=200, lr=0.01, a=0.01, b=64) | 91.080000 | 90.960000 | 8.330000 |
| PCA=175, Softmax (ep=200, lr=0.05, a=0.01, b=64) | 91.080000 | 90.970000 | 8.640000 |
| PCA=200, Softmax (ep=200, lr=0.05, a=0.01, b=128) | 91.080000 | 90.970000 | 8.730000 |
| PCA=225, Softmax (ep=100, lr=0.05, a=0.01, b=128) | 91.080000 | 90.960000 | 4.310000 |
| PCA=325, Softmax (ep=200, lr=0.05, a=0.01, b=128) | 91.080000 | 90.970000 | 10.730000 |
| PCA=325, Softmax (ep=200, lr=0.05, a=0.01, b=128) | 91.080000 | 90.970000 | 4.280000 |
| PCA=175, Softmax (ep=100, lr=0.05, a=0.01, b=64) | 91.040000 | 90.910000 | 4.180000 |
| PCA=225, Softmax (ep=200, lr=0.05, a=0.01, b=128) | 91.040000 | 90.930000 | 9.220000 |
| PCA=250, Softmax (ep=100, lr=0.05, a=0.01, b=128) | 91.040000 | 90.930000 | 4.750000 |
| PCA=250, Softmax (ep=200, lr=0.01, a=0.01, b=64) | 91.040000 | 90.930000 | 11.120000 |
| PCA=300, Softmax (ep=200, lr=0.01, a=0.01, b=64) | 91.040000 | 90.930000 | 13.820000 |
| PCA=150, Softmax (ep=100, lr=0.05, a=0.01, b=128) | 91.000000 | 90.880000 | 2.850000 |
| PCA=150, Softmax (ep=200, lr=0.05, a=0.01, b=128) | 91.000000 | 90.880000 | 6.610000 |
| PCA=175, Softmax (ep=200, lr=0.05, a=0.01, b=128) | 91.000000 | 90.880000 | 6.950000 |
| PCA=200, Softmax (ep=100, lr=0.05, a=0.01, b=64) | 91.000000 | 90.860000 | 4.560000 |
| PCA=200, Softmax (ep=100, lr=0.05, a=0.01, b=128) | 91.000000 | 90.880000 | 4.320000 |
| PCA=225, Softmax (ep=100, lr=0.01, a=0.01, b=128) | 91.000000 | 90.880000 | 4.400000 |
| PCA=250, Softmax (ep=200, lr=0.05, a=0.01, b=64) | 91.000000 | 90.900000 | 11.430000 |
| PCA=275, Softmax (ep=100, lr=0.05, a=0.01, b=64) | 91.000000 | 90.860000 | 6.120000 |
| PCA=275, Softmax (ep=200, lr=0.05, a=0.01, b=64) | 91.000000 | 90.880000 | 11.420000 |
| PCA=175, Softmax (ep=100, lr=0.01, a=0.01, b=128) | 90.960000 | 90.840000 | 3.150000 |
| PCA=325, Softmax (ep=200, lr=0.05, a=0.01, b=64) | 90.960000 | 90.840000 | 14.520000 |
| PCA=325, Softmax (ep=200, lr=0.05, a=0.01, b=64) | 90.960000 | 90.840000 | 5.050000 |
| PCA=125, Softmax (ep=100, lr=0.05, a=0.01, b=64) | 90.920000 | 90.810000 | 3.350000 |
| PCA=150, Softmax (ep=100, lr=0.01, a=0.01, b=64) | 90.920000 | 90.800000 | 3.880000 |
| PCA=275, Softmax (ep=200, lr=0.05, a=0.01, b=128) | 90.920000 | 90.800000 | 7.970000 |
| PCA=300, Softmax (ep=200, lr=0.05, a=0.01, b=128) | 90.920000 | 90.800000 | 9.260000 |
| PCA=325, Softmax (ep=100, lr=0.05, a=0.01, b=64) | 90.920000 | 90.800000 | 6.710000 |
| PCA=325, Softmax (ep=200, lr=0.01, a=0.01, b=64) | 90.920000 | 90.810000 | 13.880000 |
| PCA=325, Softmax (ep=100, lr=0.05, a=0.01, b=64) | 90.920000 | 90.800000 | 5.460000 |
| PCA=325, Softmax (ep=200, lr=0.01, a=0.01, b=64) | 90.920000 | 90.810000 | 12.980000 |
| PCA=125, Softmax (ep=100, lr=0.05, a=0.01, b=128) | 90.880000 | 90.750000 | 2.560000 |
| PCA=150, Softmax (ep=200, lr=0.01, a=0.01, b=64) | 90.880000 | 90.760000 | 7.920000 |
| PCA=150, Softmax (ep=200, lr=0.01, a=0.01, b=128) | 90.880000 | 90.760000 | 6.420000 |
| PCA=200, Softmax (ep=100, lr=0.01, a=0.01, b=64) | 90.880000 | 90.770000 | 5.090000 |
| PCA=200, Softmax (ep=200, lr=0.01, a=0.01, b=64) | 90.880000 | 90.770000 | 9.150000 |
| PCA=225, Softmax (ep=200, lr=0.05, a=0.01, b=64) | 90.880000 | 90.770000 | 10.450000 |
| PCA=250, Softmax (ep=100, lr=0.01, a=0.01, b=64) | 90.880000 | 90.770000 | 5.660000 |
| PCA=250, Softmax (ep=100, lr=0.05, a=0.01, b=64) | 90.880000 | 90.760000 | 5.620000 |
| PCA=250, Softmax (ep=200, lr=0.01, a=0.01, b=128) | 90.880000 | 90.770000 | 10.280000 |
| PCA=325, Softmax (ep=100, lr=0.05, a=0.01, b=128) | 90.880000 | 90.760000 | 5.290000 |
| PCA=325, Softmax (ep=100, lr=0.05, a=0.01, b=128) | 90.880000 | 90.760000 | 4.480000 |

Table 2 – continued from previous page

| Model Configuration (PCA, ep, lr, a, b) | Accuracy | F1-Score | Fit (s) |
|---|---|---|---|
| PCA=125, Softmax (ep=200, lr=0.05, a=0.01, b=128) | 90.840000 | 90.720000 | 6.070000 |
| PCA=150, Softmax (ep=100, lr=0.05, a=0.01, b=64) | 90.840000 | 90.720000 | 3.540000 |
| PCA=150, Softmax (ep=200, lr=0.05, a=0.01, b=64) | 90.840000 | 90.710000 | 7.810000 |
| PCA=200, Softmax (ep=200, lr=0.01, a=0.01, b=128) | 90.840000 | 90.730000 | 8.140000 |
| PCA=225, Softmax (ep=200, lr=0.01, a=0.01, b=64) | 90.840000 | 90.730000 | 10.500000 |
| PCA=250, Softmax (ep=200, lr=0.05, a=0.01, b=128) | 90.840000 | 90.730000 | 9.740000 |
| PCA=275, Softmax (ep=100, lr=0.05, a=0.01, b=128) | 90.840000 | 90.710000 | 5.520000 |
| PCA=325, Softmax (ep=100, lr=0.01, a=0.01, b=64) | 90.840000 | 90.740000 | 7.330000 |
| PCA=325, Softmax (ep=100, lr=0.01, a=0.01, b=64) | 90.840000 | 90.740000 | 3.010000 |
| PCA=100, Softmax (ep=100, lr=0.05, a=0.01, b=128) | 90.800000 | 90.680000 | 2.170000 |
| PCA=275, Softmax (ep=100, lr=0.01, a=0.01, b=64) | 90.800000 | 90.690000 | 6.340000 |
| PCA=275, Softmax (ep=200, lr=0.01, a=0.01, b=128) | 90.800000 | 90.700000 | 11.020000 |
| PCA=300, Softmax (ep=100, lr=0.01, a=0.01, b=64) | 90.800000 | 90.700000 | 7.050000 |
| PCA=300, Softmax (ep=200, lr=0.05, a=0.01, b=64) | 90.800000 | 90.670000 | 13.110000 |
| PCA=100, Softmax (ep=200, lr=0.05, a=0.01, b=64) | 90.760000 | 90.650000 | 5.010000 |
| PCA=125, Softmax (ep=200, lr=0.01, a=0.01, b=64) | 90.760000 | 90.640000 | 6.610000 |
| PCA=200, Softmax (ep=200, lr=0.05, a=0.01, b=64) | 90.760000 | 90.650000 | 9.740000 |
| PCA=225, Softmax (ep=200, lr=0.01, a=0.01, b=128) | 90.760000 | 90.650000 | 9.080000 |
| PCA=275, Softmax (ep=200, lr=0.01, a=0.01, b=64) | 90.760000 | 90.660000 | 11.870000 |
| PCA=325, Softmax (ep=100, lr=0.01, a=0.01, b=128) | 90.760000 | 90.640000 | 6.380000 |
| PCA=325, Softmax (ep=100, lr=0.01, a=0.01, b=128) | 90.760000 | 90.640000 | 2.460000 |
| PCA=125, Softmax (ep=100, lr=0.01, a=0.01, b=64) | 90.720000 | 90.590000 | 3.530000 |
| PCA=125, Softmax (ep=200, lr=0.01, a=0.01, b=128) | 90.720000 | 90.590000 | 5.210000 |
| PCA=150, Softmax (ep=100, lr=0.01, a=0.01, b=128) | 90.720000 | 90.590000 | 3.310000 |
| PCA=200, Softmax (ep=100, lr=0.01, a=0.01, b=128) | 90.720000 | 90.590000 | 3.680000 |
| PCA=250, Softmax (ep=100, lr=0.01, a=0.01, b=128) | 90.720000 | 90.610000 | 4.750000 |
| PCA=325, Softmax (ep=200, lr=0.01, a=0.01, b=128) | 90.720000 | 90.610000 | 10.110000 |
| PCA=325, Softmax (ep=200, lr=0.01, a=0.01, b=128) | 90.720000 | 90.610000 | 8.740000 |
| PCA=75, Softmax (ep=100, lr=0.05, a=0.01, b=128) | 90.680000 | 90.550000 | 1.850000 |
| PCA=125, Softmax (ep=200, lr=0.05, a=0.01, b=64) | 90.680000 | 90.550000 | 7.570000 |
| PCA=225, Softmax (ep=100, lr=0.01, a=0.01, b=64) | 90.680000 | 90.560000 | 5.310000 |
| PCA=275, Softmax (ep=100, lr=0.01, a=0.01, b=128) | 90.680000 | 90.570000 | 5.330000 |
| PCA=300, Softmax (ep=200, lr=0.01, a=0.01, b=128) | 90.680000 | 90.570000 | 10.490000 |
| PCA=300, Softmax (ep=100, lr=0.01, a=0.01, b=128) | 90.640000 | 90.540000 | 5.850000 |
| PCA=75, Softmax (ep=200, lr=0.05, a=0.01, b=128) | 90.600000 | 90.470000 | 4.280000 |
| PCA=100, Softmax (ep=100, lr=0.05, a=0.01, b=64) | 90.600000 | 90.480000 | 2.700000 |
| PCA=100, Softmax (ep=200, lr=0.05, a=0.01, b=128) | 90.520000 | 90.400000 | 4.140000 |
| PCA=125, Softmax (ep=100, lr=0.01, a=0.01, b=128) | 90.480000 | 90.340000 | 2.910000 |
| PCA=75, Softmax (ep=100, lr=0.05, a=0.01, b=64) | 90.400000 | 90.280000 | 2.040000 |
| PCA=100, Softmax (ep=200, lr=0.01, a=0.01, b=64) | 90.400000 | 90.270000 | 5.250000 |
| PCA=100, Softmax (ep=100, lr=0.01, a=0.01, b=64) | 90.320000 | 90.190000 | 2.430000 |
| PCA=75, Softmax (ep=200, lr=0.05, a=0.01, b=64) | 90.240000 | 90.090000 | 4.560000 |
| PCA=75, Softmax (ep=200, lr=0.01, a=0.01, b=64) | 90.160000 | 90.010000 | 4.900000 |
| PCA=100, Softmax (ep=100, lr=0.01, a=0.01, b=128) | 90.080000 | 89.940000 | 2.060000 |
| PCA=75, Softmax (ep=100, lr=0.01, a=0.01, b=64) | 90.040000 | 89.890000 | 1.930000 |
| PCA=75, Softmax (ep=200, lr=0.01, a=0.01, b=128) | 90.000000 | 89.840000 | 4.140000 |
| PCA=100, Softmax (ep=200, lr=0.01, a=0.01, b=128) | 90.000000 | 89.870000 | 4.410000 |
| PCA=250, Softmax (ep=200, lr=0.01, a=0.1, b=64) | 89.800000 | 89.680000 | 12.810000 |
| PCA=175, Softmax (ep=100, lr=0.01, a=0.1, b=128) | 89.760000 | 89.630000 | 3.500000 |

Table 2 – continued from previous page

| Model Configuration (PCA, ep, lr, a, b) | Accuracy | F1-Score | Fit (s) |
|---|---|---|---|
| PCA=225, Softmax (ep=200, lr=0.01, a=0.1, b=128) | 89.760000 | 89.640000 | 9.110000 |
| PCA=225, Softmax (ep=200, lr=0.05, a=0.1, b=128) | 89.760000 | 89.650000 | 9.950000 |
| PCA=250, Softmax (ep=100, lr=0.01, a=0.1, b=128) | 89.760000 | 89.630000 | 4.780000 |
| PCA=150, Softmax (ep=100, lr=0.01, a=0.1, b=64) | 89.720000 | 89.610000 | 3.750000 |
| PCA=175, Softmax (ep=100, lr=0.01, a=0.1, b=64) | 89.720000 | 89.590000 | 4.260000 |
| PCA=225, Softmax (ep=200, lr=0.01, a=0.1, b=64) | 89.720000 | 89.600000 | 10.640000 |
| PCA=250, Softmax (ep=100, lr=0.01, a=0.1, b=64) | 89.720000 | 89.590000 | 5.880000 |
| PCA=300, Softmax (ep=100, lr=0.01, a=0.1, b=64) | 89.720000 | 89.590000 | 6.480000 |
| PCA=300, Softmax (ep=200, lr=0.01, a=0.1, b=64) | 89.720000 | 89.600000 | 13.760000 |
| PCA=150, Softmax (ep=200, lr=0.05, a=0.1, b=128) | 89.680000 | 89.570000 | 6.960000 |
| PCA=200, Softmax (ep=200, lr=0.01, a=0.1, b=64) | 89.680000 | 89.560000 | 9.740000 |
| PCA=250, Softmax (ep=200, lr=0.01, a=0.1, b=128) | 89.680000 | 89.560000 | 9.890000 |
| PCA=275, Softmax (ep=200, lr=0.01, a=0.1, b=64) | 89.680000 | 89.550000 | 13.270000 |
| PCA=50, Softmax (ep=100, lr=0.05, a=0.01, b=64) | 89.640000 | 89.510000 | 1.840000 |
| PCA=150, Softmax (ep=200, lr=0.01, a=0.1, b=64) | 89.640000 | 89.530000 | 7.000000 |
| PCA=200, Softmax (ep=100, lr=0.01, a=0.1, b=64) | 89.640000 | 89.520000 | 4.610000 |
| PCA=250, Softmax (ep=200, lr=0.05, a=0.1, b=128) | 89.640000 | 89.530000 | 10.780000 |
| PCA=300, Softmax (ep=100, lr=0.01, a=0.1, b=128) | 89.640000 | 89.510000 | 5.520000 |
| PCA=325, Softmax (ep=100, lr=0.01, a=0.1, b=64) | 89.640000 | 89.510000 | 7.300000 |
| PCA=325, Softmax (ep=100, lr=0.01, a=0.1, b=64) | 89.640000 | 89.510000 | 7.000000 |
| PCA=50, Softmax (ep=200, lr=0.01, a=0.01, b=64) | 89.600000 | 89.480000 | 3.160000 |
| PCA=175, Softmax (ep=200, lr=0.01, a=0.1, b=64) | 89.600000 | 89.480000 | 8.920000 |
| PCA=175, Softmax (ep=200, lr=0.01, a=0.1, b=128) | 89.600000 | 89.480000 | 7.800000 |
| PCA=200, Softmax (ep=200, lr=0.01, a=0.1, b=128) | 89.600000 | 89.480000 | 8.390000 |
| PCA=300, Softmax (ep=200, lr=0.05, a=0.1, b=128) | 89.600000 | 89.480000 | 5.770000 |
| PCA=75, Softmax (ep=100, lr=0.01, a=0.01, b=128) | 89.560000 | 89.400000 | 1.630000 |
| PCA=200, Softmax (ep=100, lr=0.01, a=0.1, b=128) | 89.560000 | 89.430000 | 3.680000 |
| PCA=300, Softmax (ep=200, lr=0.01, a=0.1, b=128) | 89.560000 | 89.430000 | 11.960000 |
| PCA=325, Softmax (ep=100, lr=0.01, a=0.1, b=128) | 89.560000 | 89.430000 | 6.340000 |
| PCA=325, Softmax (ep=100, lr=0.01, a=0.1, b=128) | 89.560000 | 89.430000 | 5.840000 |
| PCA=125, Softmax (ep=100, lr=0.01, a=0.1, b=64) | 89.520000 | 89.410000 | 2.860000 |
| PCA=275, Softmax (ep=100, lr=0.01, a=0.1, b=64) | 89.520000 | 89.390000 | 5.980000 |
| PCA=275, Softmax (ep=200, lr=0.05, a=0.1, b=128) | 89.520000 | 89.400000 | 11.130000 |
| PCA=300, Softmax (ep=100, lr=0.05, a=0.1, b=128) | 89.520000 | 89.370000 | 6.060000 |
| PCA=325, Softmax (ep=200, lr=0.01, a=0.1, b=64) | 89.520000 | 89.390000 | 9.490000 |
| PCA=325, Softmax (ep=200, lr=0.05, a=0.1, b=128) | 89.520000 | 89.390000 | 6.300000 |
| PCA=325, Softmax (ep=200, lr=0.01, a=0.1, b=64) | 89.520000 | 89.390000 | 7.660000 |
| PCA=325, Softmax (ep=200, lr=0.05, a=0.1, b=128) | 89.520000 | 89.390000 | 8.230000 |
| PCA=50, Softmax (ep=100, lr=0.05, a=0.01, b=128) | 89.480000 | 89.350000 | 1.430000 |
| PCA=150, Softmax (ep=200, lr=0.01, a=0.1, b=128) | 89.480000 | 89.360000 | 5.960000 |
| PCA=150, Softmax (ep=200, lr=0.05, a=0.1, b=64) | 89.480000 | 89.360000 | 8.280000 |
| PCA=175, Softmax (ep=200, lr=0.05, a=0.1, b=128) | 89.480000 | 89.380000 | 7.500000 |
| PCA=225, Softmax (ep=100, lr=0.01, a=0.1, b=64) | 89.480000 | 89.350000 | 5.360000 |
| PCA=225, Softmax (ep=100, lr=0.01, a=0.1, b=128) | 89.480000 | 89.350000 | 4.320000 |
| PCA=275, Softmax (ep=200, lr=0.01, a=0.1, b=128) | 89.480000 | 89.350000 | 10.750000 |
| PCA=325, Softmax (ep=200, lr=0.01, a=0.1, b=128) | 89.480000 | 89.350000 | 6.180000 |
| PCA=325, Softmax (ep=200, lr=0.01, a=0.1, b=128) | 89.480000 | 89.350000 | 5.170000 |
| PCA=50, Softmax (ep=200, lr=0.01, a=0.01, b=128) | 89.440000 | 89.320000 | 2.880000 |
| PCA=125, Softmax (ep=100, lr=0.05, a=0.1, b=128) | 89.440000 | 89.320000 | 2.580000 |

Table 2 – continued from previous page

| Model Configuration (PCA, ep, lr, a, b) | Accuracy | F1-Score | Fit (s) |
|---|---|---|---|
| PCA=125, Softmax (ep=200, lr=0.05, a=0.1, b=64) | 89.440000 | 89.310000 | 6.460000 |
| PCA=150, Softmax (ep=100, lr=0.01, a=0.1, b=128) | 89.440000 | 89.320000 | 3.090000 |
| PCA=200, Softmax (ep=200, lr=0.05, a=0.1, b=128) | 89.440000 | 89.330000 | 8.250000 |
| PCA=275, Softmax (ep=100, lr=0.05, a=0.1, b=128) | 89.440000 | 89.310000 | 5.680000 |
| PCA=300, Softmax (ep=200, lr=0.05, a=0.1, b=64) | 89.440000 | 89.320000 | 8.910000 |
| PCA=50, Softmax (ep=200, lr=0.05, a=0.01, b=64) | 89.400000 | 89.260000 | 4.580000 |
| PCA=50, Softmax (ep=200, lr=0.05, a=0.01, b=128) | 89.400000 | 89.280000 | 3.510000 |
| PCA=150, Softmax (ep=100, lr=0.05, a=0.1, b=128) | 89.400000 | 89.290000 | 3.050000 |
| PCA=200, Softmax (ep=200, lr=0.05, a=0.1, b=64) | 89.400000 | 89.300000 | 9.040000 |
| PCA=275, Softmax (ep=100, lr=0.01, a=0.1, b=128) | 89.400000 | 89.270000 | 5.160000 |
| PCA=275, Softmax (ep=200, lr=0.05, a=0.1, b=64) | 89.400000 | 89.280000 | 12.380000 |
| PCA=325, Softmax (ep=100, lr=0.05, a=0.1, b=128) | 89.400000 | 89.260000 | 6.700000 |
| PCA=325, Softmax (ep=100, lr=0.05, a=0.1, b=128) | 89.400000 | 89.260000 | 3.380000 |
| PCA=125, Softmax (ep=200, lr=0.01, a=0.1, b=128) | 89.360000 | 89.240000 | 5.760000 |
| PCA=225, Softmax (ep=100, lr=0.05, a=0.1, b=128) | 89.360000 | 89.230000 | 4.700000 |
| PCA=50, Softmax (ep=100, lr=0.01, a=0.01, b=64) | 89.320000 | 89.190000 | 1.940000 |
| PCA=125, Softmax (ep=100, lr=0.01, a=0.1, b=128) | 89.320000 | 89.200000 | 2.430000 |
| PCA=150, Softmax (ep=100, lr=0.05, a=0.1, b=64) | 89.320000 | 89.190000 | 3.570000 |
| PCA=225, Softmax (ep=200, lr=0.05, a=0.1, b=64) | 89.320000 | 89.210000 | 11.720000 |
| PCA=325, Softmax (ep=200, lr=0.05, a=0.1, b=64) | 89.320000 | 89.180000 | 9.910000 |
| PCA=325, Softmax (ep=200, lr=0.05, a=0.1, b=64) | 89.320000 | 89.180000 | 11.820000 |
| PCA=100, Softmax (ep=100, lr=0.01, a=0.1, b=64) | 89.280000 | 89.150000 | 2.310000 |
| PCA=125, Softmax (ep=100, lr=0.05, a=0.1, b=64) | 89.280000 | 89.140000 | 3.380000 |
| PCA=125, Softmax (ep=200, lr=0.01, a=0.1, b=64) | 89.280000 | 89.170000 | 7.080000 |
| PCA=175, Softmax (ep=200, lr=0.05, a=0.1, b=64) | 89.280000 | 89.180000 | 9.000000 |
| PCA=200, Softmax (ep=100, lr=0.05, a=0.1, b=128) | 89.280000 | 89.150000 | 4.100000 |
| PCA=250, Softmax (ep=100, lr=0.05, a=0.1, b=128) | 89.280000 | 89.150000 | 5.130000 |
| PCA=250, Softmax (ep=200, lr=0.05, a=0.1, b=64) | 89.280000 | 89.170000 | 12.340000 |
| PCA=325, Softmax (ep=100, lr=0.05, a=0.1, b=64) | 89.280000 | 89.130000 | 7.480000 |
| PCA=325, Softmax (ep=100, lr=0.05, a=0.1, b=64) | 89.280000 | 89.130000 | 4.730000 |
| PCA=300, Softmax (ep=100, lr=0.05, a=0.1, b=64) | 89.240000 | 89.080000 | 6.810000 |
| PCA=100, Softmax (ep=100, lr=0.05, a=0.1, b=128) | 89.200000 | 89.060000 | 1.910000 |
| PCA=100, Softmax (ep=200, lr=0.01, a=0.1, b=128) | 89.200000 | 89.080000 | 4.910000 |
| PCA=125, Softmax (ep=200, lr=0.05, a=0.1, b=128) | 89.200000 | 89.090000 | 5.360000 |
| PCA=275, Softmax (ep=100, lr=0.05, a=0.1, b=64) | 89.200000 | 89.060000 | 6.670000 |
| PCA=100, Softmax (ep=200, lr=0.05, a=0.1, b=64) | 89.120000 | 88.980000 | 5.880000 |
| PCA=175, Softmax (ep=100, lr=0.05, a=0.1, b=128) | 89.120000 | 88.980000 | 3.420000 |
| PCA=50, Softmax (ep=100, lr=0.01, a=0.01, b=128) | 89.080000 | 88.950000 | 1.720000 |
| PCA=100, Softmax (ep=200, lr=0.01, a=0.1, b=64) | 89.080000 | 88.960000 | 5.940000 |
| PCA=30, Softmax (ep=200, lr=0.01, a=0.01, b=64) | 89.040000 | 88.890000 | 3.170000 |
| PCA=250, Softmax (ep=100, lr=0.05, a=0.1, b=64) | 89.000000 | 88.860000 | 5.700000 |
| PCA=30, Softmax (ep=200, lr=0.01, a=0.01, b=128) | 88.920000 | 88.780000 | 2.840000 |
| PCA=100, Softmax (ep=100, lr=0.01, a=0.1, b=128) | 88.920000 | 88.780000 | 1.920000 |
| PCA=100, Softmax (ep=100, lr=0.05, a=0.1, b=64) | 88.920000 | 88.770000 | 2.630000 |
| PCA=200, Softmax (ep=100, lr=0.05, a=0.1, b=64) | 88.920000 | 88.760000 | 4.730000 |
| PCA=100, Softmax (ep=200, lr=0.05, a=0.1, b=128) | 88.880000 | 88.760000 | 4.860000 |
| PCA=30, Softmax (ep=100, lr=0.05, a=0.01, b=64) | 88.840000 | 88.700000 | 1.910000 |
| PCA=30, Softmax (ep=100, lr=0.05, a=0.01, b=128) | 88.840000 | 88.700000 | 1.290000 |
| PCA=75, Softmax (ep=100, lr=0.05, a=0.1, b=64) | 88.840000 | 88.690000 | 2.400000 |

Table 2 – continued from previous page

| Model Configuration (PCA, ep, lr, a, b) | Accuracy | F1-Score | Fit (s) |
| --- | --- | --- | --- |
| PCA=30, Softmax (ep=100, lr=0.01, a=0.01, b=64) | 88.800000 | 88.650000 | 1.020000 |
| PCA=75, Softmax (ep=100, lr=0.01, a=0.1, b=128) | 88.800000 | 88.680000 | 1.950000 |
| PCA=75, Softmax (ep=100, lr=0.01, a=0.1, b=64) | 88.760000 | 88.640000 | 2.400000 |
| PCA=75, Softmax (ep=100, lr=0.05, a=0.1, b=128) | 88.760000 | 88.630000 | 1.840000 |
| PCA=75, Softmax (ep=200, lr=0.01, a=0.1, b=128) | 88.680000 | 88.560000 | 3.330000 |
| PCA=75, Softmax (ep=200, lr=0.05, a=0.1, b=128) | 88.640000 | 88.500000 | 4.400000 |
| PCA=225, Softmax (ep=100, lr=0.05, a=0.1, b=64) | 88.640000 | 88.480000 | 5.400000 |
| PCA=75, Softmax (ep=200, lr=0.01, a=0.1, b=64) | 88.600000 | 88.470000 | 4.530000 |
| PCA=30, Softmax (ep=100, lr=0.01, a=0.01, b=128) | 88.560000 | 88.400000 | 0.760000 |
| PCA=75, Softmax (ep=200, lr=0.05, a=0.1, b=64) | 88.560000 | 88.430000 | 5.470000 |
| PCA=175, Softmax (ep=100, lr=0.05, a=0.1, b=64) | 88.480000 | 88.310000 | 3.830000 |
| PCA=30, Softmax (ep=200, lr=0.05, a=0.01, b=128) | 88.360000 | 88.190000 | 2.650000 |
| PCA=30, Softmax (ep=200, lr=0.05, a=0.01, b=64) | 88.320000 | 88.160000 | 2.200000 |
| PCA=50, Softmax (ep=100, lr=0.01, a=0.1, b=64) | 88.280000 | 88.140000 | 1.180000 |
| PCA=50, Softmax (ep=100, lr=0.05, a=0.1, b=128) | 88.280000 | 88.130000 | 1.320000 |
| PCA=50, Softmax (ep=100, lr=0.05, a=0.1, b=64) | 88.160000 | 88.030000 | 2.140000 |
| PCA=50, Softmax (ep=200, lr=0.01, a=0.1, b=128) | 88.160000 | 88.030000 | 3.020000 |
| PCA=50, Softmax (ep=100, lr=0.01, a=0.1, b=128) | 88.120000 | 87.980000 | 1.190000 |
| PCA=50, Softmax (ep=200, lr=0.05, a=0.1, b=128) | 88.000000 | 87.860000 | 3.010000 |
| PCA=50, Softmax (ep=200, lr=0.01, a=0.1, b=64) | 87.960000 | 87.830000 | 3.840000 |
| PCA=50, Softmax (ep=200, lr=0.05, a=0.1, b=64) | 87.920000 | 87.750000 | 3.580000 |
| PCA=30, Softmax (ep=200, lr=0.01, a=0.1, b=64) | 87.430000 | 87.330000 | 3.620000 |
| PCA=30, Softmax (ep=100, lr=0.01, a=0.1, b=64) | 87.310000 | 87.200000 | 1.100000 |
| PCA=30, Softmax (ep=200, lr=0.01, a=0.1, b=128) | 87.310000 | 87.210000 | 2.640000 |
| PCA=30, Softmax (ep=100, lr=0.01, a=0.1, b=128) | 87.270000 | 87.150000 | 1.040000 |
| PCA=30, Softmax (ep=100, lr=0.05, a=0.1, b=128) | 86.990000 | 86.840000 | 0.760000 |
| PCA=30, Softmax (ep=200, lr=0.05, a=0.1, b=64) | 86.750000 | 86.600000 | 3.640000 |
| PCA=30, Softmax (ep=200, lr=0.05, a=0.1, b=128) | 86.750000 | 86.610000 | 2.680000 |
| PCA=30, Softmax (ep=100, lr=0.05, a=0.1, b=64) | 86.710000 | 86.540000 | 1.000000 |

Table 3: Models on LDA data Performance Comparison

| Model | Accuracy (%) | F1-Score (%) | Fit (s) |
|---|---|---|---|
| LDA + KNN (k=11, w='distance') | 88.920000 | 88.720000 | 0.000000 |
| LDA + KNN (k=7, w='distance') | 88.880000 | 88.660000 | 0.000000 |
| LDA + KNN (k=11, w='uniform') | 88.880000 | 88.670000 | 0.000000 |
| LDA + KNN (k=13, w='distance') | 88.840000 | 88.630000 | 0.000000 |
| LDA + KNN (k=9, w='distance') | 88.800000 | 88.600000 | 0.000000 |
| LDA + KNN (k=7, w='uniform') | 88.720000 | 88.510000 | 0.000000 |
| LDA + KNN (k=9, w='uniform') | 88.720000 | 88.510000 | 0.000000 |
| LDA + KNN (k=5, w='distance') | 88.680000 | 88.470000 | 0.000000 |
| LDA + KNN (k=13, w='uniform') | 88.680000 | 88.470000 | 0.000000 |
| LDA + KNN (k=15, w='uniform') | 88.600000 | 88.390000 | 0.000000 |
| LDA + KNN (k=15, w='distance') | 88.600000 | 88.400000 | 0.000000 |
| LDA + KNN (k=5, w='uniform') | 88.520000 | 88.290000 | 0.000000 |
| LDA + KNN (k=17, w='uniform') | 88.520000 | 88.310000 | 0.000000 |
| LDA + KNN (k=17, w='distance') | 88.480000 | 88.280000 | 0.000000 |
| LDA + KNN (k=19, w='distance') | 88.360000 | 88.160000 | 0.000000 |
| LDA + KNN (k=23, w='distance') | 88.240000 | 88.040000 | 0.000000 |
| LDA + KNN (k=19, w='uniform') | 88.160000 | 87.940000 | 0.000000 |
| LDA + KNN (k=21, w='distance') | 88.160000 | 87.960000 | 0.000000 |
| LDA + KNN (k=3, w='distance') | 88.080000 | 87.860000 | 0.000000 |
| LDA + KNN (k=21, w='uniform') | 88.080000 | 87.870000 | 0.000000 |
| LDA + KNN (k=23, w='uniform') | 87.960000 | 87.760000 | 0.000000 |
| LDA + KNN (k=3, w='uniform') | 87.760000 | 87.530000 | 0.000000 |
| LDA + KNN (k=1, w='uniform') | 86.430000 | 86.220000 | 0.000000 |
| LDA + KNN (k=1, w='distance') | 86.430000 | 86.220000 | 0.000000 |
| LDA + Softmax (ep=200, lr=0.08, a=0.01, b=32) | 86.190000 | 86.020000 | 5.150000 |
| LDA + Softmax (ep=150, lr=0.01, a=0.01, b=64) | 86.150000 | 85.960000 | 2.700000 |
| LDA + Softmax (ep=200, lr=0.05, a=0.01, b=32) | 86.150000 | 85.980000 | 4.970000 |
| LDA + Softmax (ep=200, lr=0.06, a=0.01, b=32) | 86.150000 | 85.980000 | 6.000000 |
| LDA + Softmax (ep=200, lr=0.07, a=0.01, b=64) | 86.150000 | 85.970000 | 3.510000 |
| LDA + Softmax (ep=200, lr=0.09, a=0.01, b=32) | 86.150000 | 85.980000 | 4.940000 |
| LDA + Softmax (ep=200, lr=0.09, a=0.01, b=64) | 86.150000 | 85.980000 | 3.280000 |
| LDA + Softmax (ep=200, lr=0.1, a=0.01, b=32) | 86.150000 | 85.980000 | 4.850000 |
| LDA + Softmax (ep=150, lr=0.03, a=0.01, b=32) | 86.110000 | 85.930000 | 3.670000 |
| LDA + Softmax (ep=150, lr=0.04, a=0.01, b=32) | 86.110000 | 85.930000 | 4.230000 |
| LDA + Softmax (ep=200, lr=0.03, a=0.01, b=32) | 86.110000 | 85.930000 | 5.310000 |
| LDA + Softmax (ep=200, lr=0.04, a=0.01, b=32) | 86.110000 | 85.940000 | 4.850000 |
| LDA + Softmax (ep=200, lr=0.05, a=0.01, b=64) | 86.110000 | 85.930000 | 3.350000 |
| LDA + Softmax (ep=200, lr=0.06, a=0.01, b=64) | 86.110000 | 85.930000 | 3.130000 |
| LDA + Softmax (ep=200, lr=0.07, a=0.01, b=32) | 86.110000 | 85.940000 | 5.480000 |
| LDA + Softmax (ep=200, lr=0.08, a=0.01, b=64) | 86.110000 | 85.940000 | 3.370000 |
| LDA + Softmax (ep=200, lr=0.1, a=0.01, b=64) | 86.110000 | 85.940000 | 3.220000 |
| LDA + Softmax (ep=250, lr=0.01, a=0.01, b=64) | 86.110000 | 85.920000 | 4.180000 |
| LDA + Softmax (ep=100, lr=0.01, a=0.01, b=32) | 86.070000 | 85.890000 | 2.560000 |
| LDA + Softmax (ep=150, lr=0.01, a=0.01, b=32) | 86.070000 | 85.890000 | 3.850000 |
| LDA + Softmax (ep=150, lr=0.02, a=0.01, b=32) | 86.070000 | 85.890000 | 3.650000 |
| LDA + Softmax (ep=150, lr=0.02, a=0.01, b=64) | 86.070000 | 85.890000 | 2.310000 |

*Continued on next page*

| Model | Accuracy (%) | F1-Score (%) | Fit (s) |
|---|---|---|---|
| LDA + Softmax (ep=200, lr=0.01, a=0.01, b=64) | 86.070000 | 85.890000 | 3.270000 |
| LDA + Softmax (ep=200, lr=0.02, a=0.01, b=32) | 86.070000 | 85.890000 | 5.210000 |
| LDA + Softmax (ep=200, lr=0.02, a=0.01, b=64) | 86.070000 | 85.890000 | 3.370000 |
| LDA + Softmax (ep=200, lr=0.03, a=0.01, b=64) | 86.070000 | 85.890000 | 3.250000 |
| LDA + Softmax (ep=200, lr=0.04, a=0.01, b=64) | 86.070000 | 85.890000 | 3.220000 |
| LDA + Softmax (ep=250, lr=0.01, a=0.01, b=32) | 86.070000 | 85.890000 | 7.280000 |
| LDA + Softmax (ep=250, lr=0.02, a=0.01, b=32) | 86.070000 | 85.890000 | 7.500000 |
| LDA + Softmax (ep=250, lr=0.02, a=0.01, b=64) | 86.070000 | 85.890000 | 4.330000 |
| LDA + Softmax (ep=250, lr=0.03, a=0.01, b=64) | 86.070000 | 85.890000 | 3.540000 |
| LDA + Softmax (ep=100, lr=0.01, a=0.01, b=64) | 86.030000 | 85.840000 | 1.590000 |
| LDA + Softmax (ep=100, lr=0.02, a=0.01, b=32) | 86.030000 | 85.850000 | 2.550000 |
| LDA + Softmax (ep=100, lr=0.02, a=0.01, b=64) | 86.030000 | 85.850000 | 1.690000 |
| LDA + Softmax (ep=100, lr=0.03, a=0.01, b=64) | 86.030000 | 85.850000 | 1.810000 |
| LDA + Softmax (ep=100, lr=0.04, a=0.01, b=64) | 86.030000 | 85.850000 | 1.740000 |
| LDA + Softmax (ep=100, lr=0.09, a=0.01, b=64) | 86.030000 | 85.860000 | 1.870000 |
| LDA + Softmax (ep=150, lr=0.03, a=0.01, b=64) | 86.030000 | 85.850000 | 2.300000 |
| LDA + Softmax (ep=150, lr=0.04, a=0.01, b=64) | 86.030000 | 85.850000 | 2.330000 |
| LDA + Softmax (ep=150, lr=0.05, a=0.01, b=32) | 86.030000 | 85.850000 | 4.370000 |
| LDA + Softmax (ep=150, lr=0.05, a=0.01, b=64) | 86.030000 | 85.850000 | 2.400000 |
| LDA + Softmax (ep=150, lr=0.06, a=0.01, b=64) | 86.030000 | 85.850000 | 2.810000 |
| LDA + Softmax (ep=150, lr=0.07, a=0.01, b=64) | 86.030000 | 85.850000 | 2.470000 |
| LDA + Softmax (ep=150, lr=0.08, a=0.01, b=64) | 86.030000 | 85.850000 | 2.500000 |
| LDA + Softmax (ep=200, lr=0.01, a=0.01, b=32) | 86.030000 | 85.850000 | 5.370000 |
| LDA + Softmax (ep=250, lr=0.03, a=0.01, b=32) | 86.030000 | 85.850000 | 6.630000 |
| LDA + Softmax (ep=250, lr=0.04, a=0.01, b=64) | 86.030000 | 85.850000 | 4.120000 |
| LDA + Softmax (ep=250, lr=0.05, a=0.01, b=64) | 86.030000 | 85.850000 | 4.010000 |
| LDA + Softmax (ep=250, lr=0.06, a=0.01, b=64) | 86.030000 | 85.850000 | 4.510000 |
| LDA + Softmax (ep=100, lr=0.05, a=0.01, b=64) | 85.990000 | 85.810000 | 1.740000 |
| LDA + Softmax (ep=100, lr=0.07, a=0.01, b=32) | 85.990000 | 85.830000 | 2.650000 |
| LDA + Softmax (ep=100, lr=0.1, a=0.01, b=64) | 85.990000 | 85.820000 | 1.800000 |
| LDA + Softmax (ep=150, lr=0.09, a=0.01, b=32) | 85.990000 | 85.810000 | 4.040000 |
| LDA + Softmax (ep=150, lr=0.09, a=0.01, b=64) | 85.990000 | 85.810000 | 2.290000 |
| LDA + Softmax (ep=150, lr=0.1, a=0.01, b=64) | 85.990000 | 85.810000 | 2.620000 |
| LDA + Softmax (ep=250, lr=0.05, a=0.01, b=32) | 85.990000 | 85.810000 | 7.410000 |
| LDA + Softmax (ep=250, lr=0.06, a=0.01, b=32) | 85.990000 | 85.810000 | 3.910000 |
| LDA + Softmax (ep=250, lr=0.07, a=0.01, b=32) | 85.990000 | 85.820000 | 5.580000 |
| LDA + Softmax (ep=250, lr=0.08, a=0.01, b=32) | 85.990000 | 85.820000 | 5.690000 |
| LDA + Softmax (ep=250, lr=0.08, a=0.01, b=64) | 85.990000 | 85.810000 | 2.850000 |
| LDA + Softmax (ep=250, lr=0.09, a=0.01, b=64) | 85.990000 | 85.810000 | 3.350000 |
| LDA + Softmax (ep=250, lr=0.1, a=0.01, b=64) | 85.990000 | 85.810000 | 3.640000 |
| LDA + Softmax (ep=100, lr=0.03, a=0.01, b=32) | 85.950000 | 85.780000 | 2.650000 |
| LDA + Softmax (ep=100, lr=0.04, a=0.01, b=32) | 85.950000 | 85.780000 | 2.800000 |
| LDA + Softmax (ep=100, lr=0.05, a=0.01, b=32) | 85.950000 | 85.780000 | 2.500000 |
| LDA + Softmax (ep=100, lr=0.06, a=0.01, b=32) | 85.950000 | 85.780000 | 2.650000 |
| LDA + Softmax (ep=100, lr=0.06, a=0.01, b=64) | 85.950000 | 85.780000 | 1.630000 |
| LDA + Softmax (ep=100, lr=0.07, a=0.01, b=64) | 85.950000 | 85.780000 | 1.660000 |
| LDA + Softmax (ep=100, lr=0.08, a=0.01, b=64) | 85.950000 | 85.780000 | 1.550000 |
| LDA + Softmax (ep=150, lr=0.06, a=0.01, b=32) | 85.950000 | 85.770000 | 3.650000 |

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| Model | Accuracy (%) | F1-Score (%) | Fit (s) |
|---|---|---|---|
| LDA + Softmax (ep=150, lr=0.07, a=0.01, b=32) | 85.950000 | 85.770000 | 3.820000 |
| LDA + Softmax (ep=150, lr=0.08, a=0.01, b=32) | 85.950000 | 85.770000 | 3.790000 |
| LDA + Softmax (ep=150, lr=0.1, a=0.01, b=32) | 85.950000 | 85.770000 | 3.760000 |
| LDA + Softmax (ep=250, lr=0.04, a=0.01, b=32) | 85.950000 | 85.770000 | 7.210000 |
| LDA + Softmax (ep=250, lr=0.07, a=0.01, b=64) | 85.950000 | 85.770000 | 2.650000 |
| LDA + Softmax (ep=250, lr=0.09, a=0.01, b=32) | 85.910000 | 85.740000 | 6.140000 |
| LDA + Softmax (ep=100, lr=0.08, a=0.01, b=32) | 85.870000 | 85.710000 | 2.900000 |
| LDA + Softmax (ep=100, lr=0.09, a=0.01, b=32) | 85.870000 | 85.710000 | 2.930000 |
| LDA + Softmax (ep=100, lr=0.1, a=0.01, b=32) | 85.870000 | 85.710000 | 2.890000 |
| LDA + Softmax (ep=250, lr=0.1, a=0.01, b=32) | 85.870000 | 85.700000 | 6.720000 |
| LDA + Softmax (ep=200, lr=0.06, a=0.1, b=64) | 84.990000 | 84.790000 | 3.370000 |
| LDA + Softmax (ep=200, lr=0.03, a=0.1, b=32) | 84.950000 | 84.750000 | 5.680000 |
| LDA + Softmax (ep=200, lr=0.05, a=0.1, b=64) | 84.950000 | 84.750000 | 3.540000 |
| LDA + Softmax (ep=200, lr=0.04, a=0.1, b=32) | 84.910000 | 84.720000 | 5.250000 |
| LDA + Softmax (ep=200, lr=0.07, a=0.1, b=64) | 84.910000 | 84.710000 | 3.330000 |
| LDA + Softmax (ep=200, lr=0.1, a=0.1, b=64) | 84.910000 | 84.710000 | 3.400000 |
| LDA + Softmax (ep=100, lr=0.08, a=0.1, b=64) | 84.870000 | 84.670000 | 1.710000 |
| LDA + Softmax (ep=100, lr=0.09, a=0.1, b=64) | 84.870000 | 84.670000 | 1.630000 |
| LDA + Softmax (ep=200, lr=0.02, a=0.1, b=32) | 84.870000 | 84.680000 | 5.160000 |
| LDA + Softmax (ep=200, lr=0.04, a=0.1, b=64) | 84.870000 | 84.670000 | 3.490000 |
| LDA + Softmax (ep=200, lr=0.05, a=0.1, b=32) | 84.870000 | 84.670000 | 5.400000 |
| LDA + Softmax (ep=200, lr=0.08, a=0.1, b=64) | 84.870000 | 84.670000 | 3.010000 |
| LDA + Softmax (ep=200, lr=0.09, a=0.1, b=64) | 84.870000 | 84.670000 | 3.620000 |
| LDA + Softmax (ep=100, lr=0.05, a=0.1, b=32) | 84.830000 | 84.630000 | 2.310000 |
| LDA + Softmax (ep=100, lr=0.07, a=0.1, b=64) | 84.830000 | 84.630000 | 1.620000 |
| LDA + Softmax (ep=100, lr=0.1, a=0.1, b=64) | 84.830000 | 84.630000 | 1.580000 |
| LDA + Softmax (ep=150, lr=0.04, a=0.1, b=64) | 84.830000 | 84.650000 | 2.500000 |
| LDA + Softmax (ep=150, lr=0.05, a=0.1, b=64) | 84.830000 | 84.650000 | 2.360000 |
| LDA + Softmax (ep=200, lr=0.03, a=0.1, b=64) | 84.830000 | 84.640000 | 3.190000 |
| LDA + Softmax (ep=200, lr=0.06, a=0.1, b=32) | 84.830000 | 84.630000 | 5.390000 |
| LDA + Softmax (ep=200, lr=0.1, a=0.1, b=32) | 84.830000 | 84.610000 | 5.110000 |
| LDA + Softmax (ep=100, lr=0.04, a=0.1, b=32) | 84.790000 | 84.590000 | 2.670000 |
| LDA + Softmax (ep=100, lr=0.06, a=0.1, b=64) | 84.790000 | 84.590000 | 1.760000 |
| LDA + Softmax (ep=100, lr=0.07, a=0.1, b=32) | 84.790000 | 84.580000 | 2.810000 |
| LDA + Softmax (ep=100, lr=0.09, a=0.1, b=32) | 84.790000 | 84.560000 | 2.470000 |
| LDA + Softmax (ep=150, lr=0.02, a=0.1, b=64) | 84.790000 | 84.600000 | 2.570000 |
| LDA + Softmax (ep=150, lr=0.04, a=0.1, b=32) | 84.790000 | 84.600000 | 3.860000 |
| LDA + Softmax (ep=150, lr=0.06, a=0.1, b=64) | 84.790000 | 84.600000 | 2.240000 |
| LDA + Softmax (ep=200, lr=0.01, a=0.1, b=32) | 84.790000 | 84.590000 | 5.220000 |
| LDA + Softmax (ep=200, lr=0.01, a=0.1, b=64) | 84.790000 | 84.590000 | 3.090000 |
| LDA + Softmax (ep=200, lr=0.02, a=0.1, b=64) | 84.790000 | 84.590000 | 3.050000 |
| LDA + Softmax (ep=200, lr=0.07, a=0.1, b=32) | 84.790000 | 84.590000 | 4.830000 |
| LDA + Softmax (ep=200, lr=0.09, a=0.1, b=32) | 84.790000 | 84.570000 | 5.500000 |
| LDA + Softmax (ep=100, lr=0.02, a=0.1, b=32) | 84.750000 | 84.540000 | 2.690000 |
| LDA + Softmax (ep=100, lr=0.04, a=0.1, b=64) | 84.750000 | 84.540000 | 1.640000 |
| LDA + Softmax (ep=100, lr=0.05, a=0.1, b=64) | 84.750000 | 84.550000 | 1.630000 |
| LDA + Softmax (ep=100, lr=0.06, a=0.1, b=32) | 84.750000 | 84.550000 | 2.560000 |
| LDA + Softmax (ep=100, lr=0.08, a=0.1, b=32) | 84.750000 | 84.530000 | 2.390000 |

*Continued on next page*

| Model | Accuracy (%) | F1-Score (%) | Fit (s) |
|---|---|---|---|
| LDA + Softmax (ep=150, lr=0.01, a=0.1, b=32) | 84.750000 | 84.560000 | 4.220000 |
| LDA + Softmax (ep=150, lr=0.01, a=0.1, b=64) | 84.750000 | 84.550000 | 2.350000 |
| LDA + Softmax (ep=150, lr=0.03, a=0.1, b=32) | 84.750000 | 84.560000 | 3.710000 |
| LDA + Softmax (ep=150, lr=0.03, a=0.1, b=64) | 84.750000 | 84.560000 | 2.560000 |
| LDA + Softmax (ep=150, lr=0.07, a=0.1, b=64) | 84.750000 | 84.560000 | 2.200000 |
| LDA + Softmax (ep=100, lr=0.01, a=0.1, b=64) | 84.710000 | 84.510000 | 1.740000 |
| LDA + Softmax (ep=100, lr=0.03, a=0.1, b=32) | 84.710000 | 84.510000 | 2.850000 |
| LDA + Softmax (ep=100, lr=0.1, a=0.1, b=32) | 84.710000 | 84.480000 | 2.800000 |
| LDA + Softmax (ep=150, lr=0.02, a=0.1, b=32) | 84.710000 | 84.520000 | 4.000000 |
| LDA + Softmax (ep=150, lr=0.06, a=0.1, b=32) | 84.710000 | 84.530000 | 4.100000 |
| LDA + Softmax (ep=150, lr=0.08, a=0.1, b=64) | 84.710000 | 84.520000 | 2.530000 |
| LDA + Softmax (ep=150, lr=0.09, a=0.1, b=64) | 84.710000 | 84.530000 | 2.470000 |
| LDA + Softmax (ep=200, lr=0.08, a=0.1, b=32) | 84.710000 | 84.500000 | 5.690000 |
| LDA + Softmax (ep=250, lr=0.01, a=0.1, b=64) | 84.710000 | 84.510000 | 4.330000 |
| LDA + Softmax (ep=250, lr=0.02, a=0.1, b=32) | 84.710000 | 84.510000 | 6.880000 |
| LDA + Softmax (ep=250, lr=0.03, a=0.1, b=32) | 84.710000 | 84.510000 | 5.440000 |
| LDA + Softmax (ep=250, lr=0.04, a=0.1, b=32) | 84.710000 | 84.500000 | 5.660000 |
| LDA + Softmax (ep=250, lr=0.05, a=0.1, b=32) | 84.710000 | 84.510000 | 5.510000 |
| LDA + Softmax (ep=100, lr=0.03, a=0.1, b=64) | 84.670000 | 84.460000 | 1.620000 |
| LDA + Softmax (ep=150, lr=0.05, a=0.1, b=32) | 84.670000 | 84.480000 | 3.820000 |
| LDA + Softmax (ep=150, lr=0.08, a=0.1, b=32) | 84.670000 | 84.490000 | 3.840000 |
| LDA + Softmax (ep=150, lr=0.1, a=0.1, b=64) | 84.670000 | 84.490000 | 2.490000 |
| LDA + Softmax (ep=250, lr=0.01, a=0.1, b=32) | 84.670000 | 84.470000 | 6.650000 |
| LDA + Softmax (ep=250, lr=0.02, a=0.1, b=64) | 84.670000 | 84.470000 | 4.910000 |
| LDA + Softmax (ep=250, lr=0.03, a=0.1, b=64) | 84.670000 | 84.470000 | 4.210000 |
| LDA + Softmax (ep=250, lr=0.04, a=0.1, b=64) | 84.670000 | 84.470000 | 3.310000 |
| LDA + Softmax (ep=250, lr=0.05, a=0.1, b=64) | 84.670000 | 84.470000 | 3.400000 |
| LDA + Softmax (ep=250, lr=0.06, a=0.1, b=32) | 84.670000 | 84.470000 | 6.850000 |
| LDA + Softmax (ep=250, lr=0.06, a=0.1, b=64) | 84.670000 | 84.470000 | 3.710000 |
| LDA + Softmax (ep=100, lr=0.01, a=0.1, b=32) | 84.630000 | 84.430000 | 2.900000 |
| LDA + Softmax (ep=100, lr=0.02, a=0.1, b=64) | 84.630000 | 84.430000 | 1.820000 |
| LDA + Softmax (ep=150, lr=0.07, a=0.1, b=32) | 84.630000 | 84.440000 | 4.460000 |
| LDA + Softmax (ep=250, lr=0.07, a=0.1, b=32) | 84.630000 | 84.430000 | 7.260000 |
| LDA + Softmax (ep=250, lr=0.07, a=0.1, b=64) | 84.630000 | 84.430000 | 3.630000 |
| LDA + Softmax (ep=250, lr=0.08, a=0.1, b=64) | 84.630000 | 84.430000 | 4.490000 |
| LDA + Softmax (ep=250, lr=0.08, a=0.1, b=32) | 84.590000 | 84.390000 | 3.560000 |
| LDA + Softmax (ep=250, lr=0.09, a=0.1, b=64) | 84.590000 | 84.390000 | 2.260000 |
| LDA + Softmax (ep=250, lr=0.1, a=0.1, b=64) | 84.590000 | 84.390000 | 2.650000 |
| LDA + Softmax (ep=150, lr=0.09, a=0.1, b=32) | 84.550000 | 84.370000 | 3.900000 |
| LDA + Softmax (ep=150, lr=0.1, a=0.1, b=32) | 84.550000 | 84.380000 | 3.850000 |
| LDA + Softmax (ep=250, lr=0.09, a=0.1, b=32) | 84.550000 | 84.350000 | 4.850000 |
| LDA + Softmax (ep=250, lr=0.1, a=0.1, b=32) | 84.470000 | 84.270000 | 5.420000 |