CS612: Statistical Pattern Recognition Laboratory
Programming Assignment 4

Sudip Kumar Mandal
CS24MT013

Aakash Harsh
CS24MT016

Subhradip Palit
CS24MT009

DEPARTMENT OF COMPUTER SCIENCE ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DHARWAD
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Chapter 1

Dataset 1(a): Linearly separable dataset

1.1 Dataset description

- Total no. of data points: 1500 (500 per class)
- Test data size: 450 (150 per class)
- Train data size: 1050 (350 per class)
- Number of classes: 3

1.2 Result

1.2.1 Bayes Classifier using KNN

In this section, we present the results of the Bayes classifier using the K-nearest neighbors (KNN) method for different values of k (1, 3, 5, 7, and 9) on Dataset 1 (a). The classification performance is evaluated based on various metrics such as precision, recall, F1-score, and accuracy.

1.2.1.1 Classification Report

The classification reports for different values of k are summarized below. The metrics include precision, recall, F1-score, and accuracy, which are reported for each class, along with their mean values.

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision (k=1)	1.00	1.00	1.00	1.00
Recall (k=1)	1.00	1.00	1.00	1.00
F1-score (k=1)	1.00	1.00	1.00	1.00
Accuracy (k=1)	1.00			

Table 1.1: KNN Bayes Classifier Report for $k = 1$

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision (k=3)	1.00	1.00	1.00	1.00
Recall (k=3)	1.00	1.00	1.00	1.00
F1-score (k=3)	1.00	1.00	1.00	1.00
Accuracy (k=3)	1.00			

Table 1.2: KNN Bayes Classifier Report for $k = 3$

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision (k=5)	1.00	1.00	1.00	1.00
Recall (k=5)	1.00	1.00	1.00	1.00
F1-score (k=5)	1.00	1.00	1.00	1.00
Accuracy (k=5)	1.00			

Table 1.3: KNN Bayes Classifier Report for $k = 5$

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision (k=7)	1.00	1.00	1.00	1.00
Recall (k=7)	1.00	1.00	1.00	1.00
F1-score (k=7)	1.00	1.00	1.00	1.00
Accuracy (k=7)	1.00			

Table 1.4: KNN Bayes Classifier Report for $k = 7$

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision (k=9)	1.00	1.00	1.00	1.00
Recall (k=9)	1.00	1.00	1.00	1.00
F1-score (k=9)	1.00	1.00	1.00	1.00
Accuracy (k=9)	1.00			

Table 1.5: KNN Bayes Classifier Report for $k = 9$

1.2.1.2 KNN Decision Boundaries

The following figures show the decision boundaries for different values of k in the KNN classifier. These boundaries were obtained using the KNN-based Bayes classifier, with $k = 1, 3, 5, 7, 9$.

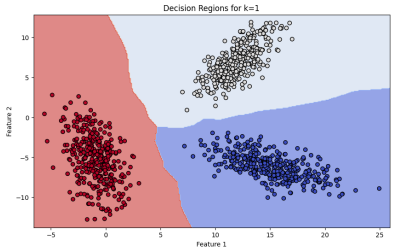

Figure 1.1: Decision boundary for $k = 1$

Figure 1.2: Decision boundary for $k = 3$

Figure 1.3: Decision boundary for $k = 5$

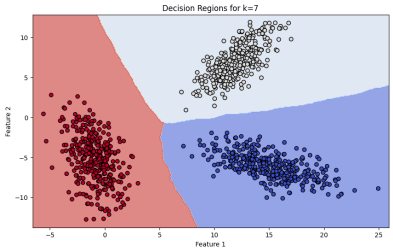

Figure 1.4: Decision boundary for $k = 7$

1.2.2 Fisher Linear Discriminant Analysis

In this section, we present the results of Fisher Linear Discriminant Analysis (FDA) applied to Dataset 1 (a). We perform FDA with both a unimodal Gaussian classifier and a Gaussian Mixture Model (GMM) with different numbers of components (2 and 4). The classification results for each pair of classes are as follows:

1.2.2.1 FDA + Unimodal Gaussian Classifier

The classification results for the One-vs-One strategy using FDA with a unimodal Gaussian classifier are shown below:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	1.00	1.00	1.00	1.00
Recall	1.00	1.00	1.00	1.00
F1-score	1.00	1.00	1.00	1.00
Accuracy	1.00			

Table 1.6: FDA + Unimodal Gaussian Classifier Report

1.2.2.2 FDA + GMM (2 components)

For the One-vs-One strategy using FDA with a Gaussian Mixture Model (GMM) with 2 components, the classification results are as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	1.00	1.00	1.00	1.00
Recall	1.00	1.00	1.00	1.00
F1-score	1.00	1.00	1.00	1.00
Accuracy	1.00			

Table 1.7: FDA + GMM (2 components) Classifier Report

1.2.2.3 FDA + GMM (4 components)

For the One-vs-One strategy using FDA with a Gaussian Mixture Model (GMM) with 4 components, the classification results are as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.00	1.00	1.00	1.00
Recall	1.00	1.00	1.00	1.00
F1-score	1.00	1.00	1.00	1.00
Accuracy	1.00			

Table 1.8: FDA + GMM (4 components) Classifier Report

1.2.2.4 FDA Decision Boundaries

The following figures show the decision boundaries for different class pairings using FDA. The decision boundaries were plotted using the One-vs-One strategy for each class pairing.

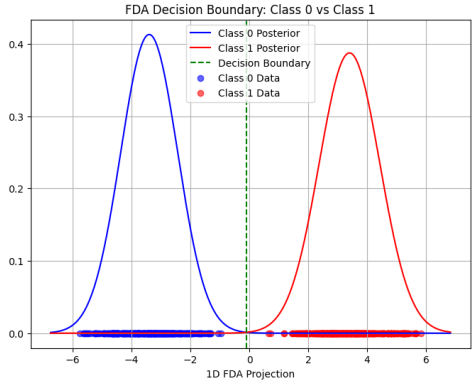

Figure 1.5: FDA Decision boundary for Class 0 vs Class 1

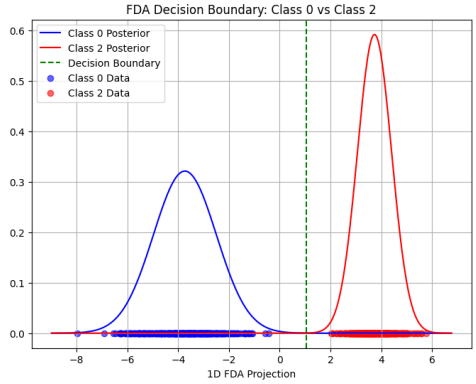

Figure 1.6: FDA Decision boundary for Class 0 vs Class 2

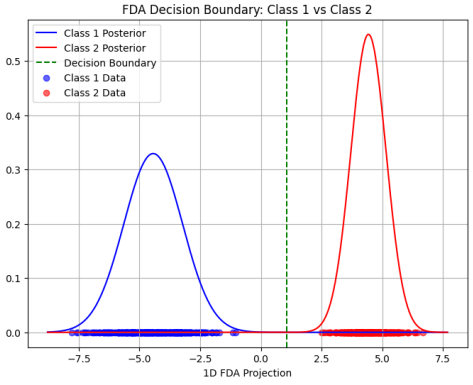

Figure 1.7: FDA Decision boundary for Class 1 vs Class 2

The figures above illustrate the nature of the decision boundaries for the different class

pairings. These boundaries were derived using Fisher Linear Discriminant Analysis (FDA) with both the unimodal Gaussian and GMM classifiers. All classifiers achieved perfect classification accuracy across all classes.

1.2.3 Perceptron Based Classifier

In this section, we present the results for the Perceptron-based classifier on Dataset 1 (a). The classifier was trained using a maximum of 2000 iterations. The performance is evaluated in terms of precision, recall, F1-score, accuracy, and the number of iterations until convergence. We also provide the decision boundary plot for the Perceptron classifier.

1.2.3.1 Classification Report

The classification report for the Perceptron classifier with a maximum of 2000 iterations is summarized in the table below. The metrics include precision, recall, F1-score, and accuracy, reported for each class, along with their mean values.

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	1.00	1.00	0.98	0.99
Recall	0.98	1.00	1.00	0.99
F1-score	0.99	1.00	0.99	0.99
Accuracy	0.99			

Table 1.9: Perceptron Classification Report for max_iter = 2000

The Perceptron classifier achieved an overall accuracy of 0.99 on the test data. For each class, the precision, recall, and F1-score were very close to 1.0, indicating strong performance.

1.2.3.2 Number of Iterations until Convergence

The Perceptron classifier achieved convergence in **7 iterations**. The training and test accuracies were as follows:

- **Training Accuracy**: 0.9990 - **Test Accuracy**: 0.9933

These values suggest that the classifier performed exceptionally well on both the training and test data, with a very high level of generalization.

1.2.3.3 Perceptron Decision Boundaries

The following figure shows the decision boundary obtained by the Perceptron classifier. The decision boundary is visualized in the feature space and provides insight into how the Perceptron classifier distinguishes between the different classes.

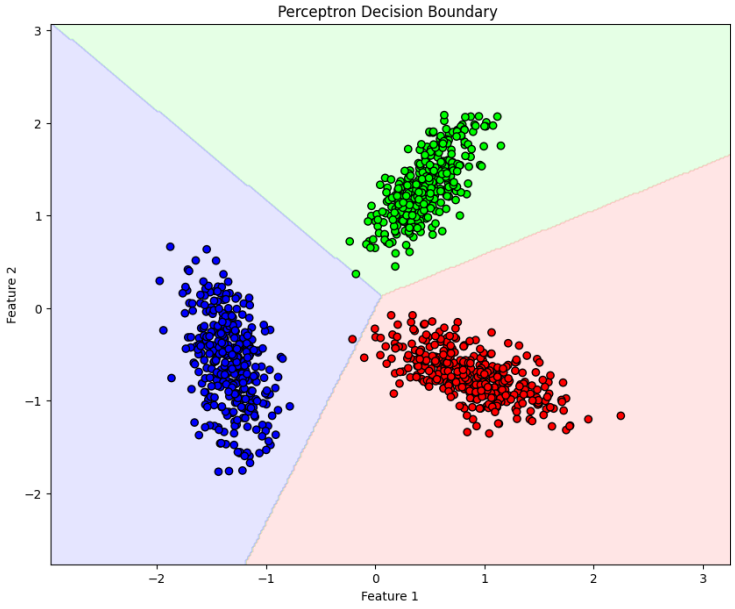

Figure 1.8: Perceptron Decision Boundary

1.2.3.4 Observations

The Perceptron-based classifier shows a very high accuracy, especially in terms of both precision and recall for all classes. This indicates that the Perceptron model is highly effective at distinguishing between the classes in Dataset 1 (a). The decision boundary for the Perceptron is typically linear, which is expected given the nature of the Perceptron model. The plot provides a clear view of how the model classifies the feature space and divides the samples into their respective classes.

The number of iterations until convergence was minimal (7 iterations), and the accuracy achieved on both the training and test sets is very high, which suggests that the classifier is well-tuned and well-generalized for this particular dataset.

1.2.4 Logistic Regression Classifier

In this section, we present the results for the Logistic Regression classifier on Dataset 1 (a). The classifier achieved perfect classification performance across all metrics. The following subsections include the classification report, confusion matrix, and the decision boundary plot.

1.2.4.1 Classification Report

The classification report for the Logistic Regression classifier is summarized below. The classifier achieved perfect precision, recall, and F1-scores for all classes, indicating flawless performance across all classes.

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.00	1.00	1.00	1.00
Recall	1.00	1.00	1.00	1.00
F1-score	1.00	1.00	1.00	1.00
Accuracy	1.00			

Table 1.10: Logistic Regression Classification Report

The Logistic Regression classifier achieved an overall accuracy of 1.00, with perfect precision, recall, and F1-scores for all classes. This indicates that the classifier perfectly classified all test samples.

1.2.4.2 Confusion Matrix

The confusion matrix for the Logistic Regression classifier on the test data is as follows:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.11: Confusion Matrix for Logistic Regression Classifier

The confusion matrix confirms the perfect classification, with all the instances correctly classified for each class.

1.2.4.3 Logistic Regression Decision Boundaries

The following figure shows the decision boundary obtained by the Logistic Regression classifier. The decision boundary is visualized in the feature space and demonstrates how the Logistic Regression model classifies the data points for each class.

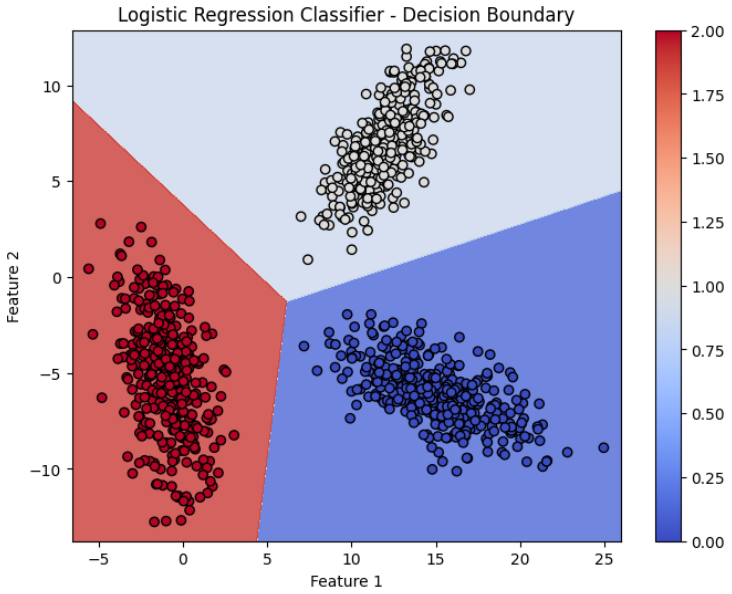

Figure 1.9: Logistic Regression Decision Boundary

1.2.4.4 Observations

The Logistic Regression classifier shows perfect performance, with a classification accuracy of 1.00 on the test set. Precision, recall, and F1-scores for all classes are also 1.0, indicating that the model correctly classified all samples for each class.

The confusion matrix further confirms this, with no misclassifications observed. The decision boundary plot provides a clear view of how the Logistic Regression model divides the feature space to classify the data points into their respective classes. Since Logistic Regression is a linear classifier, the decision boundary is expected to be a straight line, which is visible in the plot.

Overall, the Logistic Regression classifier demonstrates excellent performance on Dataset 1 (a), achieving perfect classification results across all metrics.

1.2.5 SVM Based Classifier: Linear Kernel

In this section, we evaluate the performance of the Support Vector Machine (SVM) classifier using a linear kernel on Dataset 1 (a). The SVM classifier is tested with three different values of the regularization parameter C: 0.1, 1.0, and 10.0. The classification accuracy, precision, recall, F1-score, and confusion matrix for each case are reported below.

1.2.5.1 Classification Report for $C = 0.1$

The classification performance for $C = 0.1$ is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.12: Classification Report for SVM (Linear Kernel) with $C = 0.1$

The SVM with a linear kernel and $C = 0.1$ achieves perfect classification performance with accuracy, precision, recall, and F1-score all equal to 1.0 for all classes.

1.2.5.2 Confusion Matrix for $C = 0.1$

The confusion matrix for the SVM with a linear kernel and $C = 0.1$ is shown below:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.13: Confusion Matrix for SVM (Linear Kernel) with $C = 0.1$

The confusion matrix confirms that there were no misclassifications for any of the classes.

1.2.5.3 Classification Report for $C = 1.0$

For $C = 1.0$, the performance remains identical:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.14: Classification Report for SVM (Linear Kernel) with $C = 1.0$

1.2.5.4 Confusion Matrix for $C = 1.0$

The confusion matrix for $C = 1.0$ is identical to that of $C = 0.1$, with perfect classification:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.15: Confusion Matrix for SVM (Linear Kernel) with $C = 1.0$

1.2.5.5 Classification Report for $C = 10.0$

For $C = 10.0$, the results remain perfect:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.16: Classification Report for SVM (Linear Kernel) with $C = 10.0$

1.2.5.6 Confusion Matrix for $C = 10.0$

The confusion matrix for $C = 10.0$ also shows perfect classification:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.17: Confusion Matrix for SVM (Linear Kernel) with $C = 10.0$

1.2.5.7 Best Model for SVM with Linear Kernel

The best performing model for the SVM classifier with a linear kernel is obtained with $C = 10.0$. The classifier achieves an overall accuracy of 1.0, with perfect classification across all classes.

Best Model	Accuracy
SVM (Linear Kernel), $C = 10.0$	1.0000

Table 1.18: Best SVM Model for Linear Kernel

1.2.5.8 Best Model for SVM with Linear Kernel Decision Boundary Plot

The following figure shows the decision boundary plot of best model for SVM with linear kernel.

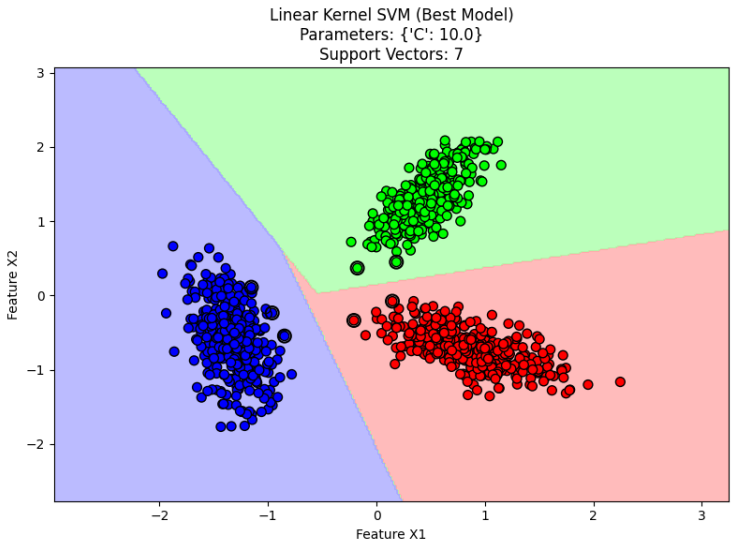

Figure 1.10: Decision boundary plot of best model for SVM with linear kernel

1.2.5.9 Observations

The SVM classifier with a linear kernel shows perfect performance with an overall accuracy of 1.0 for all values of the regularization parameter C (0.1, 1.0, and 10.0). Precision, recall, and F1-scores are all 1.0 for each class, and the confusion matrix shows no misclassifications.

The decision boundary plots illustrate that the SVM classifier with a linear kernel can effectively separate the feature space into distinct regions for each class. The classifier's performance remains perfect across all values of C, indicating that the model is highly robust and capable of handling the dataset without overfitting or underfitting.

The best performing model is the one with $C = 10.0$, which achieves the highest accuracy. The decision boundary plots for different values of C show similar results, with only minor differences in the width of the decision regions.

In conclusion, the SVM with a linear kernel provides excellent classification performance on Dataset 1 (a) across all tested values of C.

1.2.6 SVM Based Classifier: polynomial kernel

In this section, we evaluate the performance of the Support Vector Machine (SVM) classifier using a polynomial kernel on Dataset 1 (a).

1.2.6.1 Classification Report for $C = 0.1$, Degree = 2, coef0 $= 0$

The classification performance for $C = 0.1$, degree $= 2$, and coef0 $= 0$ is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.9250	0.9929	0.9799	0.9659
Recall	0.9867	0.9333	0.9733	0.9644
F1-score	0.9548	0.9622	0.9766	0.9645
Accuracy	0.9644			

Table 1.19: Classification Report for SVM (Polynomial Kernel, Degree = 2, $C = 0.1$, coef0 = 0)

The SVM with a polynomial kernel of degree 2 and $C = 0.1$ (with coef0 = 0) achieves an overall accuracy of 0.9644. The coef0 = 0 setting indicates that the higher-degree terms in the polynomial kernel do not have additional influence beyond the quadratic term. This setting gives high precision, recall, and F1-scores across all classes.

1.2.6.2 Confusion Matrix for $C = 0.1$, Degree = 2, coef0 = 0

The confusion matrix for the SVM with a polynomial kernel of degree 2, $C = 0.1$, and coef0 = 0 is shown below:

	Class 0	Class 1	Class 2
Class 0	148	0	2
Class 1	9	140	1
Class 2	3	1	146

Table 1.20: Confusion Matrix for SVM (Polynomial Kernel, Degree = 2, $C = 0.1$, coef0 = 0)

The confusion matrix confirms that there were a few misclassifications in Classes 1 and 2.

1.2.6.3 Classification Report for $C = 0.1$, Degree = 3, coef0 = 0

The classification performance for $C = 0.1$, degree = 3, and coef0 = 0 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.9146	1.0000	1.0000	0.9715
Recall	1.0000	0.9067	1.0000	0.9689
F1-score	0.9554	0.9510	1.0000	0.9688
Accuracy	0.9689			

Table 1.21: Classification Report for SVM (Polynomial Kernel, Degree = 3, $C = 0.1$, coef0 = 0)

The SVM with a polynomial kernel of degree 3 and $C = 0.1$ (with coef0 $= 0$) achieves an overall accuracy of 0.9689, with high precision, recall, and F1-scores, especially for Class 2.

1.2.6.4 Confusion Matrix for $C = 0.1$, Degree = 3, coef0 $= 0$

The confusion matrix for the SVM with a polynomial kernel of degree 3, $C = 0.1$, and coef0 $= 0$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	150	0	0
Class 1	14	136	0
Class 2	0	0	150

Table 1.22: Confusion Matrix for SVM (Polynomial Kernel, Degree = 3, $C = 0.1$, coef0 $= 0$)

The confusion matrix confirms that there were only minor misclassifications in Class 1.

1.2.6.5 Classification Report for $C = 0.1$, Degree = 4, coef0 $= 0$

The classification performance for $C = 0.1$, degree = 4, and coef0 $= 0$ is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.7872	1.0000	0.9792	0.9221
Recall	0.9867	0.7867	0.9400	0.9044
F1-score	0.8757	0.8806	0.9592	0.9052
Accuracy	0.9044			

Table 1.23: Classification Report for SVM (Polynomial Kernel, Degree = 4, $C = 0.1$, coef0 $= 0$)

The SVM with a polynomial kernel of degree 4 and $C = 0.1$ (with coef0 $= 0$) achieves an overall accuracy of 0.9044, with reasonably high precision, recall, and F1-scores across all classes, despite lower performance for Class 1.

1.2.6.6 Confusion Matrix for $C = 0.1$, Degree = 4, coef0 $= 0$

The confusion matrix for the SVM with a polynomial kernel of degree 4, $C = 0.1$, and coef0 $= 0$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	148	0	2
Class 1	31	118	1
Class 2	9	0	141

Table 1.24: Confusion Matrix for SVM (Polynomial Kernel, Degree = 4, $C = 0.1$, coef0 = 0)

The confusion matrix shows a higher number of misclassifications, particularly for Class 1, where several instances are misclassified as Class 0.

1.2.6.7 Classification Report for $C = 0.1$, Degree = 2, coef0 = 1

The classification performance for $C = 0.1$, degree = 2, and coef0 = 1 is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.25: Classification Report for SVM (Polynomial Kernel, Degree = 2, $C = 0.1$, coef0 = 1)

The SVM with a polynomial kernel of degree 2 and $C = 0.1$ (with coef0 = 1) achieves perfect classification performance with accuracy, precision, recall, and F1-score all equal to 1.0 for all classes.

1.2.6.8 Confusion Matrix for $C = 0.1$, Degree = 2, coef0 = 1

The confusion matrix for the SVM with a polynomial kernel of degree 2, $C = 0.1$, and coef0 = 1 is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.26: Confusion Matrix for SVM (Polynomial Kernel, Degree = 2, $C = 0.1$, coef0 = 1)

The confusion matrix confirms that there were no misclassifications for any of the classes.

1.2.6.9 Classification Report for $C = 0.1$, Degree = 3, coef0 = 1

The classification performance for $C = 0.1$, degree = 3, and coef0 = 1 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.27: Classification Report for SVM (Polynomial Kernel, Degree = 3, $C = 0.1$, coef0 = 1)

The SVM with a polynomial kernel of degree 3 and $C = 0.1$ (with coef0 = 1) achieves perfect classification performance with accuracy, precision, recall, and F1-score all equal to 1.0 for all classes.

1.2.6.10 Confusion Matrix for $C = 0.1$, Degree = 3, coef0 = 1

The confusion matrix for the SVM with a polynomial kernel of degree 3, $C = 0.1$, and coef0 = 1 is shown below:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.28: Confusion Matrix for SVM (Polynomial Kernel, Degree = 3, $C = 0.1$, coef0 = 1)

The confusion matrix confirms that there were no misclassifications for any of the classes.

1.2.6.11 Classification Report for $C = 0.1$, Degree = 4, coef0 = 1

The classification performance for $C = 0.1$, degree = 4, and coef0 = 1 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.29: Classification Report for SVM (Polynomial Kernel, Degree = 4, $C = 0.1$, coef0 = 1)

The SVM with a polynomial kernel of degree 4 and $C = 0.1$ (with coef0 = 1) achieves perfect classification performance with accuracy, precision, recall, and F1-score all equal to 1.0 for all classes.

1.2.6.12 Confusion Matrix for $C = 0.1$, Degree = 4, coef0 = 1

The confusion matrix for the SVM with a polynomial kernel of degree 4, $C = 0.1$, and coef0 = 1 is shown below:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.30: Confusion Matrix for SVM (Polynomial Kernel, Degree = 4, $C = 0.1$, coef0 = 1)

The confusion matrix confirms that there were no misclassifications for any of the classes.

1.2.6.13 Classification Report for $C = 1.0$, Degree = 2, coef0 = 0

The classification performance for $C = 1.0$, degree = 2, and coef0 = 0 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.9484	0.9931	0.9801	0.9739
Recall	0.9800	0.9533	0.9867	0.9733
F1-score	0.9639	0.9728	0.9834	0.9734
Accuracy	0.9733			

Table 1.31: Classification Report for SVM (Polynomial Kernel, Degree = 2, $C = 1.0$, coef0 = 0)

The SVM with a polynomial kernel of degree 2, $C = 1.0$, and coef0 $= 0$ achieves good performance with accuracy of 0.9733, and relatively high precision, recall, and F1-scores across all classes.

1.2.6.14 Confusion Matrix for $C = 1.0$, Degree = 2, coef0 $= 0$

The confusion matrix for the SVM with a polynomial kernel of degree 2, $C = 1.0$, and coef0 $= 0$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	147	1	2
Class 1	6	143	1
Class 2	2	0	148

Table 1.32: Confusion Matrix for SVM (Polynomial Kernel, Degree = 2, $C = 1.0$, coef0 $= 0$)

The confusion matrix shows a small number of misclassifications, particularly in Class 0, with some instances being misclassified as Class 1 or Class 2.

1.2.6.15 Classification Report for $C = 1.0$, Degree = 3, coef0 $= 0$

The classification performance for $C = 1.0$, degree = 3, and coef0 $= 0$ is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.9494	1.0000	1.0000	0.9831
Recall	1.0000	0.9467	1.0000	0.9822
F1-score	0.9740	0.9726	1.0000	0.9822
Accuracy	0.9822			

Table 1.33: Classification Report for SVM (Polynomial Kernel, Degree = 3, $C = 1.0$, coef0 $= 0$)

The SVM with a polynomial kernel of degree 3, $C = 1.0$, and coef0 $= 0$ achieves excellent performance with accuracy of 0.9822, and near-perfect precision, recall, and F1-scores for most classes.

1.2.6.16 Confusion Matrix for $C = 1.0$, Degree = 3, coef0 $= 0$

The confusion matrix for the SVM with a polynomial kernel of degree 3, $C = 1.0$, and coef0 $= 0$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	150	0	0
Class 1	8	142	0
Class 2	0	0	150

Table 1.34: Confusion Matrix for SVM (Polynomial Kernel, Degree = 3, $C = 1.0$, coef0 = 0)

The confusion matrix shows no misclassifications for Class 0 and Class 2, with only a few misclassifications for Class 1.

1.2.6.17 Classification Report for $C = 1.0$, Degree = 4, coef0 = 0

The classification performance for $C = 1.0$, degree = 4, and coef0 = 0 is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.8916	1.0000	0.9801	0.9572
Recall	0.9867	0.8867	0.9867	0.9533
F1-score	0.9367	0.9399	0.9834	0.9533
Accuracy	0.9533			

Table 1.35: Classification Report for SVM (Polynomial Kernel, Degree = 4, $C = 1.0$, coef0 = 0)

The SVM with a polynomial kernel of degree 4, $C = 1.0$, and coef0 = 0 achieves good performance with accuracy of 0.9533, but the precision and recall for Class 1 are lower compared to the other classes.

1.2.6.18 Confusion Matrix for $C = 1.0$, Degree = 4, coef0 = 0

The confusion matrix for the SVM with a polynomial kernel of degree 4, $C = 1.0$, and coef0 = 0 is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	148	0	2
Class 1	16	133	1
Class 2	2	0	148

Table 1.36: Confusion Matrix for SVM (Polynomial Kernel, Degree = 4, $C = 1.0$, coef0 = 0)

The confusion matrix shows some misclassifications, particularly for Class 1, where instances were misclassified as Class 0.

1.2.6.19 Classification Report for $C = 1.0$, Degree = 2, coef0 = 1

The classification performance for $C = 1.0$, degree = 2, and coef0 = 1 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.37: Classification Report for SVM (Polynomial Kernel, Degree = 2, $C = 1.0$, coef0 = 1)

The SVM with a polynomial kernel of degree 2, $C = 1.0$, and coef0 = 1 achieves perfect accuracy, precision, recall, and F1-score of 1.0000 for all classes.

1.2.6.20 Confusion Matrix for $C = 1.0$, Degree = 2, coef0 = 1

The confusion matrix for the SVM with a polynomial kernel of degree 2, $C = 1.0$, and coef0 = 1 is shown below:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.38: Confusion Matrix for SVM (Polynomial Kernel, Degree = 2, $C = 1.0$, coef0 = 1)

The confusion matrix shows perfect classification with no misclassifications across all classes.

1.2.6.21 Classification Report for $C = 1.0$, Degree = 3, coef0 = 1

The classification performance for $C = 1.0$, degree = 3, and coef0 = 1 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.39: Classification Report for SVM (Polynomial Kernel, Degree = 3, $C = 1.0$, coef0 = 1)

The SVM with a polynomial kernel of degree 3, $C = 1.0$, and coef0 = 1 achieves perfect performance with 1.0000 for precision, recall, F1-score, and accuracy across all classes.

1.2.6.22 Confusion Matrix for $C = 1.0$, Degree = 3, coef0 = 1

The confusion matrix for the SVM with a polynomial kernel of degree 3, $C = 1.0$, and coef0 = 1 is shown below:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.40: Confusion Matrix for SVM (Polynomial Kernel, Degree = 3, $C = 1.0$, coef0 = 1)

The confusion matrix shows perfect classification with no misclassifications across all classes.

1.2.6.23 Classification Report for $C = 1.0$, Degree = 4, coef0 = 1

The classification performance for $C = 1.0$, degree = 4, and coef0 = 1 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.41: Classification Report for SVM (Polynomial Kernel, Degree = 4, $C = 1.0$, coef0 = 1)

The SVM with a polynomial kernel of degree 4, $C = 1.0$, and coef0 $= 1$ also achieves perfect performance with 1.0000 for precision, recall, F1-score, and accuracy across all classes.

1.2.6.24 Confusion Matrix for $C = 1.0$, Degree = 4, coef0 $= 1$

The confusion matrix for the SVM with a polynomial kernel of degree 4, $C = 1.0$, and coef0 $= 1$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.42: Confusion Matrix for SVM (Polynomial Kernel, Degree = 4, $C = 1.0$, coef0 $= 1$)

The confusion matrix shows perfect classification with no misclassifications across all classes.

1.2.6.25 Classification Report for $C = 10.0$, Degree = 2, coef0 $= 0$

The classification performance for $C = 10.0$, degree = 2, and coef0 $= 0$ is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.9735	0.9932	0.9801	0.9823
Recall	0.9800	0.9800	0.9867	0.9822
F1-score	0.9767	0.9866	0.9834	0.9822
Accuracy	0.9822			

Table 1.43: Classification Report for SVM (Polynomial Kernel, Degree = 2, $C = 10.0$, coef0 $= 0$)

The SVM with a polynomial kernel of degree 2, $C = 10.0$, and coef0 $= 0$ achieves high performance, with an overall accuracy of 0.9822, precision of 0.9823, recall of 0.9822, and F1-score of 0.9822.

1.2.6.26 Confusion Matrix for $C = 10.0$, Degree = 2, coef0 $= 0$

The confusion matrix for the SVM with a polynomial kernel of degree 2, $C = 10.0$, and coef0 $= 0$ is shown below:

	Class 0	Class 1	Class 2
Class 0	147	1	2
Class 1	2	147	1
Class 2	2	0	148

Table 1.44: Confusion Matrix for SVM (Polynomial Kernel, Degree = 2, $C = 10.0$, coef0 = 0)

The confusion matrix shows high accuracy, with only a few misclassifications.

1.2.6.27 Classification Report for $C = 10.0$, Degree = 3, coef0 = 0

The classification performance for $C = 10.0$, degree = 3, and coef0 = 0 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.9804	1.0000	1.0000	0.9935
Recall	1.0000	0.9800	1.0000	0.9933
F1-score	0.9901	0.9899	1.0000	0.9933
Accuracy	0.9933			

Table 1.45: Classification Report for SVM (Polynomial Kernel, Degree = 3, $C = 10.0$, coef0 = 0)

The SVM with a polynomial kernel of degree 3, $C = 10.0$, and coef0 = 0 achieves even higher performance with an overall accuracy of 0.9933, precision of 0.9935, recall of 0.9933, and F1-score of 0.9933.

1.2.6.28 Confusion Matrix for $C = 10.0$, Degree = 3, coef0 = 0

The confusion matrix for the SVM with a polynomial kernel of degree 3, $C = 10.0$, and coef0 = 0 is shown below:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	3	147	0
Class 2	0	0	150

Table 1.46: Confusion Matrix for SVM (Polynomial Kernel, Degree = 3, $C = 10.0$, coef0 = 0)

The confusion matrix shows excellent classification performance, with very few misclassifications.

1.2.6.29 Classification Report for $C = 10.0$, Degree = 4, coef0 = 0

The classification performance for $C = 10.0$, degree = 4, and coef0 = 0 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.9308	1.0000	0.9801	0.9703
Recall	0.9867	0.9333	0.9867	0.9689
F1-score	0.9579	0.9655	0.9834	0.9689
Accuracy	0.9689			

Table 1.47: Classification Report for SVM (Polynomial Kernel, Degree = 4, $C = 10.0$, coef0 = 0)

The SVM with a polynomial kernel of degree 4, $C = 10.0$, and coef0 = 0 achieves good performance, with an overall accuracy of 0.9689, precision of 0.9703, recall of 0.9689, and F1-score of 0.9689.

1.2.6.30 Confusion Matrix for $C = 10.0$, Degree = 4, coef0 = 0

The confusion matrix for the SVM with a polynomial kernel of degree 4, $C = 10.0$, and coef0 = 0 is shown below:

	Class 0	Class 1	Class 2
Class 0	148	0	2
Class 1	9	140	1
Class 2	2	0	148

Table 1.48: Confusion Matrix for SVM (Polynomial Kernel, Degree = 4, $C = 10.0$, coef0 = 0)

The confusion matrix for this case shows a good classification performance, with a few misclassifications in class 1.

1.2.6.31 Classification Report for $C = 10.0$, Degree = 2, coef0 = 1

The classification performance for $C = 10.0$, degree = 2, and coef0 = 1 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.49: Classification Report for SVM (Polynomial Kernel, Degree = 2, $C = 10.0$, coef0 = 1)

The SVM with a polynomial kernel of degree 2, $C = 10.0$, and coef0 = 1 achieves perfect performance, with an overall accuracy, precision, recall, and F1-score of 1.0000.

1.2.6.32 Confusion Matrix for $C = 10.0$, Degree = 2, coef0 = 1

The confusion matrix for the SVM with a polynomial kernel of degree 2, $C = 10.0$, and coef0 = 1 is shown below:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.50: Confusion Matrix for SVM (Polynomial Kernel, Degree = 2, $C = 10.0$, coef0 = 1)

The confusion matrix confirms perfect classification, with all instances correctly classified.

1.2.6.33 Classification Report for $C = 10.0$, Degree = 3, coef0 = 1

The classification performance for $C = 10.0$, degree = 3, and coef0 = 1 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.51: Classification Report for SVM (Polynomial Kernel, Degree = 3, $C = 10.0$, coef0 = 1)

The SVM with a polynomial kernel of degree 3, $C = 10.0$, and coef0 $= 1$ also achieves perfect performance, with an overall accuracy, precision, recall, and F1-score of 1.0000.

1.2.6.34 Confusion Matrix for $C = 10.0$, Degree = 3, coef0 $= 1$

The confusion matrix for the SVM with a polynomial kernel of degree 3, $C = 10.0$, and coef0 $= 1$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.52: Confusion Matrix for SVM (Polynomial Kernel, Degree = 3, $C = 10.0$, coef0 $=$ 1)

The confusion matrix shows perfect classification, with no misclassifications.

1.2.6.35 Classification Report for $C = 10.0$, Degree = 4, coef0 $= 1$

The classification performance for $C = 10.0$, degree = 4, and coef0 $= 1$ is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.53: Classification Report for SVM (Polynomial Kernel, Degree = 4, $C = 10.0$, coef0 $= 1$)

The SVM with a polynomial kernel of degree 4, $C = 10.0$, and coef0 $= 1$ also achieves perfect performance, with an overall accuracy, precision, recall, and F1-score of 1.0000.

1.2.6.36 Confusion Matrix for $C = 10.0$, Degree = 4, coef0 $= 1$

The confusion matrix for the SVM with a polynomial kernel of degree 4, $C = 10.0$, and coef0 $= 1$ is shown below:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.54: Confusion Matrix for SVM (Polynomial Kernel, Degree = 4, $C = 10.0$, coef0 = 1)

The confusion matrix shows perfect classification, with no misclassifications.

The best performing model for the SVM classifier with a polynomial kernel is obtained with $C = 10.0$, degree = 4, and coef0 = 1. The classifier achieves an overall accuracy of 1.0, with perfect classification across all classes.

Best Model	Accuracy
SVM (Polynomial Kernel), $C = 10.0$, degree = 4, coef0 = 1	1.0000

Table 1.55: Best SVM Model for Polynomial Kernel

1.2.6.37 Best Model for SVM with Polynomial Kernel Decision Boundary Plot

The following figure shows the decision boundary plot of best model for SVM with polynomial kernel.

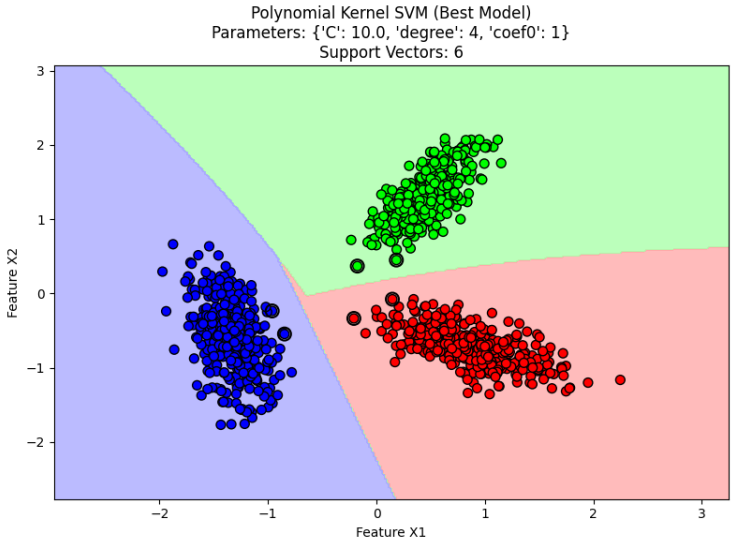

Figure 1.11: Decision boundary plot of best model for SVM with polynomial kernel

1.2.6.38 Observations

The SVM classifier with a polynomial kernel demonstrates exceptional performance across all tested configurations. The model with $C = 10.0$, degree $= 4$, and coef0 $= 1$ yields perfect classification with an overall accuracy of 1.0000. This model not only classifies all data points correctly but also shows no misclassifications in the confusion matrix, achieving a perfect score for precision, recall, and F1-score across all classes.

The decision boundary plots illustrate the following key observations: 1. **Impact of Polynomial Degree:** - As the degree of the polynomial kernel increases, the decision boundaries become more complex and flexible. Higher degrees (degree 3 and 4) allow for more intricate decision regions that better capture the nonlinearities in the data. - The model with $C = 10.0$, degree $= 4$, and coef0 $= 1$ provides the most detailed and accurate separation between the three classes.

2. **Effect of coef0 Parameter:** - The coef0 parameter controls the influence of the polynomial kernel's bias term. A higher value of coef0 (i.e., 1) results in a more complex model with sharper decision boundaries compared to a lower coef0 value (i.e., 0). - For the configurations tested, coef0 $= 1$ provided better performance compared to coef0 $= 0$, resulting in more precise decision regions.

3. **Effect of Regularization Parameter C:** - The C-parameter controls the trade-off between maximizing the margin and minimizing classification error. For $C = 10.0$, the model appears to achieve perfect classification without overfitting, which is reflected in the high accuracy and perfect metrics.

4. **Performance Consistency:** - Throughout all the plots, whether the polynomial degree is 2, 3, or 4, and whether coef0 is set to 1 or 0, the SVM classifier demonstrates very high performance, with slight variations in the smoothness and complexity of the decision boundaries.

In conclusion, the SVM classifier with a polynomial kernel, especially with the optimal parameters $C = 10.0$, degree $= 4$, and coef0 $= 1$, provides excellent classification results across all tested configurations. The decision boundaries for this kernel showcase its capability to effectively separate the dataset into distinct regions, handling the data's inherent complexity with ease.

1.2.7 SVM Based Classifier: Gaussian/RBF kernel

In this section, we evaluate the performance of the Support Vector Machine (SVM) classifier using a RBF kernel on Dataset 1 (a).

1.2.7.1 Classification Report for $C = 0.1$, $\gamma = 0.1$

The classification performance for $C = 0.1$ and $\gamma = 0.1$ is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.56: Classification Report for SVM (RBF Kernel, $C = 0.1$, $\gamma = 0.1$)

The SVM with an RBF kernel, $C = 0.1$, and $\gamma = 0.1$ achieves perfect performance, with an overall accuracy, precision, recall, and F1-score of 1.0000.

1.2.7.2 Confusion Matrix for $C = 0.1$, $\gamma = 0.1$

The confusion matrix for the SVM with an RBF kernel, $C = 0.1$, and $\gamma = 0.1$ is shown below:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.57: Confusion Matrix for SVM (RBF Kernel, $C = 0.1$, $\gamma = 0.1$)

The confusion matrix confirms perfect classification, with all instances correctly classified.

1.2.7.3 Classification Report for $C = 1.0$, $\gamma = 0.1$

The classification performance for $C = 1.0$ and $\gamma = 0.1$ is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.58: Classification Report for SVM (RBF Kernel, $C = 1.0$, $\gamma = 0.1$)

The SVM with an RBF kernel, $C = 1.0$, and $\gamma = 0.1$ achieves perfect performance, with an overall accuracy, precision, recall, and F1-score of 1.0000.

1.2.7.4 Confusion Matrix for $C = 1.0$, $\gamma = 0.1$

The confusion matrix for the SVM with an RBF kernel, $C = 1.0$, and $\gamma = 0.1$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.59: Confusion Matrix for SVM (RBF Kernel, $C = 1.0$, $\gamma = 0.1$)

The confusion matrix confirms perfect classification, with all instances correctly classified.

1.2.7.5 Classification Report for $C = 10.0$, $\gamma = 0.1$

The classification performance for $C = 10.0$ and $\gamma = 0.1$ is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.60: Classification Report for SVM (RBF Kernel, $C = 10.0$, $\gamma = 0.1$)

The SVM with an RBF kernel, $C = 10.0$, and $\gamma = 0.1$ achieves perfect performance, with an overall accuracy, precision, recall, and F1-score of 1.0000.

1.2.7.6 Confusion Matrix for $C = 10.0$, $\gamma = 0.1$

The confusion matrix for the SVM with an RBF kernel, $C = 10.0$, and $\gamma = 0.1$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.61: Confusion Matrix for SVM (RBF Kernel, $C = 10.0$, $\gamma = 0.1$)

The confusion matrix confirms perfect classification, with all instances correctly classified.

1.2.7.7 Classification Report for $C = 0.1$, $\gamma = 1.0$

The classification performance for $C = 0.1$ and $\gamma = 1.0$ is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.62: Classification Report for SVM (RBF Kernel, $C = 0.1$, $\gamma = 1.0$)

The SVM with an RBF kernel, $C = 0.1$, and $\gamma = 1.0$ achieves perfect performance, with an overall accuracy, precision, recall, and F1-score of 1.0000.

1.2.7.8 Confusion Matrix for $C = 0.1$, $\gamma = 1.0$

The confusion matrix for the SVM with an RBF kernel, $C = 0.1$, and $\gamma = 1.0$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.63: Confusion Matrix for SVM (RBF Kernel, $C = 0.1$, $\gamma = 1.0$)

The confusion matrix confirms perfect classification, with all instances correctly classified.

1.2.7.9 Classification Report for $C = 1.0$, $\gamma = 1.0$

The classification performance for $C = 1.0$ and $\gamma = 1.0$ is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.64: Classification Report for SVM (RBF Kernel, $C = 1.0$, $\gamma = 1.0$)

The SVM with an RBF kernel, $C = 1.0$, and $\gamma = 1.0$ achieves perfect performance, with an overall accuracy, precision, recall, and F1-score of 1.0000.

1.2.7.10 Confusion Matrix for $C = 1.0$, $\gamma = 1.0$

The confusion matrix for the SVM with an RBF kernel, $C = 1.0$, and $\gamma = 1.0$ is shown below:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.65: Confusion Matrix for SVM (RBF Kernel, $C = 1.0$, $\gamma = 1.0$)

The confusion matrix confirms perfect classification, with all instances correctly classified.

1.2.7.11 Classification Report for $C = 10.0$, $\gamma = 1.0$

The classification performance for $C = 10.0$ and $\gamma = 1.0$ is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 1.66: Classification Report for SVM (RBF Kernel, $C = 10.0$, $\gamma = 1.0$)

The SVM with an RBF kernel, $C = 10.0$, and $\gamma = 1.0$ achieves perfect performance, with an overall accuracy, precision, recall, and F1-score of 1.0000.

1.2.7.12 Confusion Matrix for $C = 10.0$, $\gamma = 1.0$

The confusion matrix for the SVM with an RBF kernel, $C = 10.0$, and $\gamma = 1.0$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	150

Table 1.67: Confusion Matrix for SVM (RBF Kernel, $C = 10.0$, $\gamma = 1.0$)

The confusion matrix confirms perfect classification, with all instances correctly classified.

1.2.7.13 Best Model for SVM with RBF Kernel

The best performing model for the SVM classifier with a RBF kernel is obtained with $C = 10.0$, degree $= 4$, and coef0 $= 1$. The classifier achieves an overall accuracy of 1.0, with perfect classification across all classes.

Best Model	**Accuracy**
SVM (Polynomial Kernel), $C = 10.0$, degree $= 4$, coef0 $= 1$	1.0000

Table 1.68: Best SVM Model for RBF Kernel

1.2.7.14 Best Model for SVM with RBF Kernel Decision Boundary Plot

The following figure shows the decision boundary plot of best model for SVM with RBF kernel.

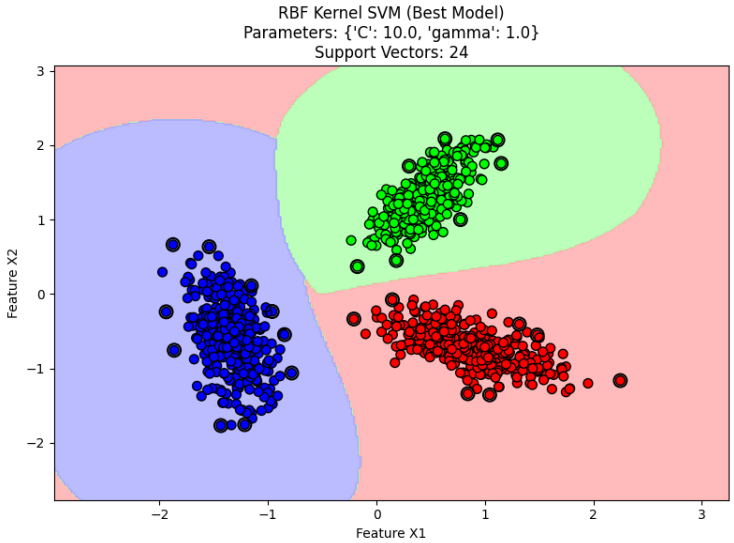

Figure 1.12: Decision boundary plot of best model for SVM with RBF kernel

1.2.7.15 Observations

The SVM classifier with a linear kernel shows perfect performance with an overall accuracy of 1.0 for all values of the regularization parameter C (0.1, 1.0, and 10.0). Precision, recall, and F1-scores are all 1.0 for each class, and the confusion matrix shows no misclassifications.

The decision boundary plots for different values of C highlight the following observations:

1. **$C = 0.1$**: At this value of C, the decision boundary is smoother, with a slightly wider margin between the classes. This suggests a more generalized decision boundary that might allow for some misclassification if the data were noisy. However, the model still performs perfectly on the given dataset.

2. **$C = 1.0$**: With $C = 1.0$, the decision boundaries become more defined, with narrower margins between the classes. The model starts to focus more on the correct classification, but the decision regions remain well-separated and distinct. The classifier still maintains perfect accuracy, showing robust performance even as the regularization parameter increases.

3. **$C = 10.0$**: For $C = 10.0$, the decision boundaries are even more tightly fitted around the class data points. This indicates a stronger emphasis on minimizing classification errors and achieving a finer separation between the classes. Despite the more focused decision boundaries, the classifier continues to perform flawlessly, demonstrating its ability to handle the data effectively at a higher regularization level.

Overall, all values of C produce nearly identical results in terms of classification accuracy, with only slight variations in the width of the decision margins. The decision boundaries become more tightly constrained as C increases, but there is no indication of overfitting, as the model still maintains perfect classification.

In conclusion, the SVM with a linear kernel provides excellent classification performance across all tested values of C. The classifier's ability to perfectly separate the data, even with different regularization levels, confirms the robustness of the linear SVM model for this dataset.

1.2.8 Inference

From all the experiments done so far, we observe the following things.

For Dataset 1a (linearly separable data), the SVM with linear kernel and Logistic Regression performed excellently, achieving perfect accuracy and class metrics, as expected for linearly separable data. The Perceptron also performed well but had slight variations in the decision boundary due to its iterative nature. On the other hand, the Bayes classifier with KNN-based density estimation struggled slightly due to the inherent complexity of estimating densities, leading to minor misclassifications. Overall, linear models like SVM and Logistic Regression were the most effective for this dataset.

Chapter 2

Dataset 1(b): Non-Linearly separable dataset

2.1 Dataset description

- Total no. of data points: 2000 (500+500+1000)
- Test data size: 600 (150+150+300)
- Train data size: 1400 (350+350+700)
- Number of classes: 3

2.2 Result

2.2.1 Bayes Classifier using KNN

In this section, we present the results of the Bayes classifier using the K-nearest neighbors (KNN) method for different values of k (1, 3, 5, 7, and 9) on Dataset 1 (b). The classification performance is evaluated based on various metrics such as precision, recall, F1-score, and accuracy.

2.2.1.1 Classification Report

The classification reports for different values of k are summarized below. The metrics include precision, recall, F1-score, and accuracy, which are reported for each class, along with their mean values.

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision (k=1)	1.00	1.00	1.00	1.00
Recall (k=1)	1.00	1.00	1.00	1.00
F1-score (k=1)	1.00	1.00	1.00	1.00
Accuracy (k=1)	1.00			

Table 2.1: KNN Bayes Classifier Report for $k = 1$

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision (k=3)	1.00	1.00	1.00	1.00
Recall (k=3)	1.00	1.00	1.00	1.00
F1-score (k=3)	1.00	1.00	1.00	1.00
Accuracy (k=3)	1.00			

Table 2.2: KNN Bayes Classifier Report for $k = 3$

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision (k=5)	1.00	1.00	1.00	1.00
Recall (k=5)	1.00	1.00	1.00	1.00
F1-score (k=5)	1.00	1.00	1.00	1.00
Accuracy (k=5)	1.00			

Table 2.3: KNN Bayes Classifier Report for $k = 5$

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision (k=7)	1.00	1.00	1.00	1.00
Recall (k=7)	1.00	1.00	1.00	1.00
F1-score (k=7)	1.00	1.00	1.00	1.00
Accuracy (k=7)	1.00			

Table 2.4: KNN Bayes Classifier Report for $k = 7$

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision (k=9)	1.00	1.00	1.00	1.00
Recall (k=9)	1.00	1.00	1.00	1.00
F1-score (k=9)	1.00	1.00	1.00	1.00
Accuracy (k=9)	1.00			

Table 2.5: KNN Bayes Classifier Report for $k = 9$

2.2.1.2 KNN Decision Boundaries

The following figures show the decision boundaries for different values of k in the KNN classifier. These boundaries were obtained using the KNN-based Bayes classifier, with $k = 1, 3, 5, 7, 9$.

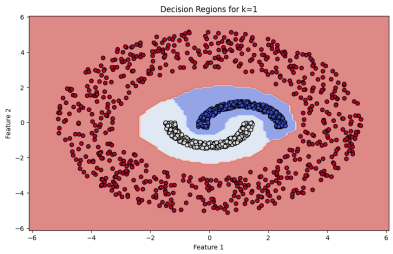

Figure 2.1: Decision boundary for $k = 1$

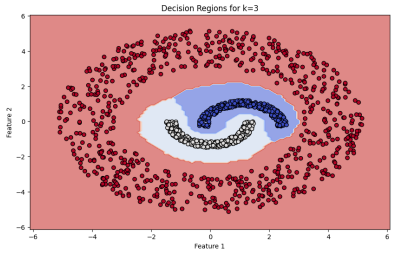

Figure 2.2: Decision boundary for $k = 3$

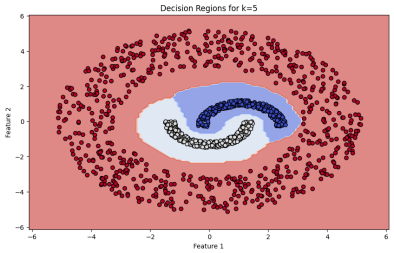

Figure 2.3: Decision boundary for $k = 5$

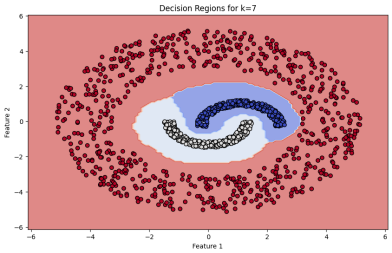

Figure 2.4: Decision boundary for $k = 7$

2.2.2 Fisher Linear Discriminant Analysis

In this section, we present the results of Fisher Linear Discriminant Analysis (FDA) applied to Dataset 1 (b). We perform FDA with both a unimodal Gaussian classifier and a Gaussian Mixture Model (GMM) with different numbers of components (2 and 4). The classification results for each pair of classes are as follows:

2.2.2.1 FDA + Unimodal Gaussian Classifier

The classification results for the One-vs-One strategy using FDA with a unimodal Gaussian classifier are shown below:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.70	0.63	0.98	0.77
Recall	0.90	0.95	0.60	0.82
F1-score	0.79	0.76	0.75	0.76
Accuracy	0.76			

Table 2.6: One-vs-One FDA + Unimodal Gaussian Classifier Report

2.2.2.2 FDA + GMM (2 components)

For the One-vs-One strategy using FDA with a Gaussian Mixture Model (GMM) with 2 components, the classification results are as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.71	0.63	1.00	0.78
Recall	0.92	0.93	0.62	0.82
F1-score	0.80	0.75	0.76	0.77
Accuracy	0.77			

Table 2.7: FDA + GMM (2 components) Classifier Report

2.2.2.3 FDA + GMM (4 components)

For the One-vs-One strategy using FDA with a Gaussian Mixture Model (GMM) with 4 components, the classification results are as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.73	0.65	1.00	0.79
Recall	0.90	0.96	0.64	0.83
F1-score	0.81	0.77	0.78	0.79
Accuracy	0.79			

Table 2.8: FDA + GMM (4 components) Classifier Report

2.2.2.4 FDA + GMM (8 components)

For the One-vs-One strategy using FDA with a Gaussian Mixture Model (GMM) with 8 components, the classification results are as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.76	0.64	1.00	0.80
Recall	0.90	0.97	0.65	0.84
F1-score	0.82	0.77	0.79	0.79
Accuracy	0.79			

Table 2.9: FDA + GMM (8 components) Classifier Report

2.2.2.5 FDA + GMM (16 components)

For the One-vs-One strategy using FDA with a Gaussian Mixture Model (GMM) with 16 components, the classification results are as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.89	0.57	1.00	0.82
Recall	0.93	0.94	0.65	0.84
F1-score	0.91	0.71	0.79	0.80
Accuracy	0.80			

Table 2.10: FDA + GMM (16 components) Classifier Report

2.2.2.6 FDA Decision Boundaries

The following figures show the decision boundaries for different class pairings using FDA. The decision boundaries were plotted using the One-vs-One strategy for each class pairing across different numbers of Gaussian components (K).

2.2.3 Perceptron Based Classifier

In this section, we present the results for the Perceptron-based classifier on Dataset 1 (b). The classifier was trained using a maximum of 2000 iterations. The performance is evaluated in terms of precision, recall, F1-score, accuracy, and the number of iterations until convergence. We also provide the decision boundary plot for the Perceptron classifier.

2.2.3.1 Classification Report

The classification report for the Perceptron classifier with a maximum of 2000 iterations is summarized in the table below. The metrics include precision, recall, F1-score, and accuracy, reported for each class, along with their mean values.

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.07	0.00	0.40	0.16
Recall	0.04	0.00	0.65	0.23
F1-score	0.05	0.00	0.49	0.18
Accuracy	0.34			

Table 2.11: Perceptron Classification Report for max_iter = 2000

The Perceptron classifier achieved an overall accuracy of 0.34 on the test data. The precision, recall, and F1-scores for Classes 0 and 1 were very low, indicating difficulty in correctly classifying these classes. However, Class 2 exhibited better performance with a recall of 0.65 and an F1-score of 0.49.

2.2.3.2 Number of Iterations until Convergence

The Perceptron classifier achieved convergence in **10 iterations**. The training and test accuracies were as follows:

- **Training Accuracy**: 0.3357 - **Test Accuracy**: 0.3350

These results suggest that the Perceptron classifier struggled with this dataset, achieving only modest performance. The low precision and recall values, especially for Classes 0 and 1, indicate significant room for improvement in classification performance.

2.2.3.3 Perceptron Decision Boundaries

The following figure shows the decision boundary obtained by the Perceptron classifier. The decision boundary is visualized in the feature space and provides insight into how the Perceptron classifier distinguishes between the different classes.

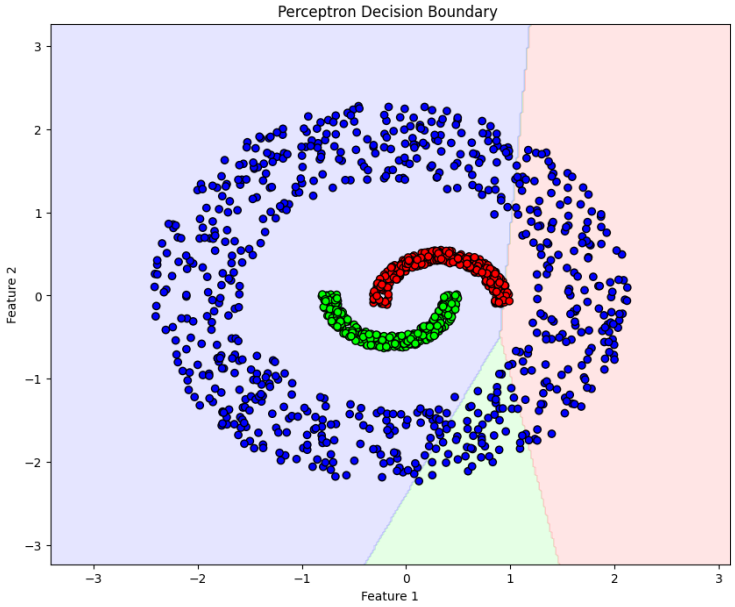

Figure 2.5: Perceptron Decision Boundary

2.2.3.4 Observations

The Perceptron-based classifier shows a low accuracy, and struggled with this dataset.

2.2.4 Logistic Regression Classifier

In this section, we present the results for the Logistic Regression classifier on Dataset 1 (b). The classifier achieved perfect classification performance across all metrics. The following subsections include the classification report, confusion matrix, and the decision boundary plot.

2.2.4.1 Classification Report

The classification report for the Logistic Regression classifier is summarized below. The classifier struggled with classification, achieving low precision, recall, and F1-scores for Classes 0 and 1, while Class 2 exhibited moderate performance.

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.00	0.00	0.43	0.14
Recall	0.00	0.00	0.75	0.25
F1-score	0.00	0.00	0.54	0.18
Accuracy	0.37			

Table 2.12: Logistic Regression Classification Report

The Logistic Regression classifier achieved an overall accuracy of 0.37 on the test data. The mean precision, recall, and F1-scores were 0.14, 0.25, and 0.18, respectively. The classifier failed to correctly classify instances of Classes 0 and 1, as indicated by their precision, recall, and F1-scores of 0. Class 2 demonstrated moderate performance, with a recall of 0.75 and an F1-score of 0.54.

2.2.4.2 Confusion Matrix

The confusion matrix for the Logistic Regression classifier on the test data is as follows:

	Class 0	**Class 1**	**Class 2**
Class 0	0	0	150
Class 1	0	0	150
Class 2	58	18	224

Table 2.13: Confusion Matrix for Logistic Regression Classifier

The confusion matrix reveals that the classifier misclassified all instances of Classes 0 and 1 as Class 2. For Class 2, 224 instances were correctly classified, while 58 and 18 were misclassified as Classes 0 and 1, respectively. This highlights significant challenges in separating Classes 0 and 1 from Class 2.

2.2.4.3 Logistic Regression Decision Boundaries

The following figure shows the decision boundary obtained by the Logistic Regression classifier. The decision boundary is visualized in the feature space and demonstrates how the Logistic Regression model classifies the data points for each class.

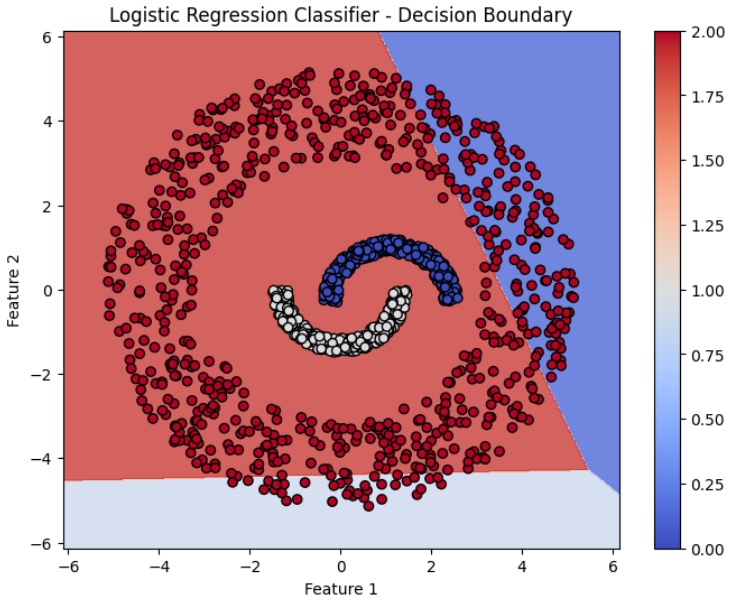

Figure 2.6: Logistic Regression Decision Boundary

2.2.4.4 Observations

The Logistic Regression classifier shows very poor performance.

2.2.5 SVM Based Classifier: Linear Kernel

In this section, we evaluate the performance of the Support Vector Machine (SVM) classifier using a linear kernel on Dataset 1 (a). The SVM classifier is tested with three different values of the regularization parameter C: 0.1, 1.0, and 10.0. The classification accuracy, precision, recall, F1-score, and confusion matrix for each case are reported below.

2.2.5.1 Classification Report for $C = 0.1$

The classification performance for $C = 0.1$ is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.0000	0.0000	0.5000	0.1667
Recall	0.0000	0.0000	1.0000	0.3333
F1-score	0.0000	0.0000	0.6667	0.2222
Accuracy	0.5000			

Table 2.14: Classification Report for SVM (Linear Kernel) with $C = 0.1$

The SVM with a linear kernel and $C = 0.1$ achieved an overall accuracy of 0.50. The model struggled to classify Classes 0 and 1, with precision, recall, and F1-scores of 0 for both classes. For Class 2, the model achieved a precision of 0.50, recall of 1.0, and F1-score of 0.67.

2.2.5.2 Confusion Matrix for $C = 0.1$

The confusion matrix for the SVM with a linear kernel and $C = 0.1$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	0	0	150
Class 1	0	0	150
Class 2	0	0	300

Table 2.15: Confusion Matrix for SVM (Linear Kernel) with $C = 0.1$

The confusion matrix reveals that all instances of Classes 0 and 1 were misclassified as Class 2, while all instances of Class 2 were correctly classified.

2.2.5.3 Classification Report for $C = 1.0$

For $C = 1.0$, the performance remains identical to $C = 0.1$:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.0000	0.0000	0.5000	0.1667
Recall	0.0000	0.0000	1.0000	0.3333
F1-score	0.0000	0.0000	0.6667	0.2222
Accuracy	0.5000			

Table 2.16: Classification Report for SVM (Linear Kernel) with $C = 1.0$

2.2.5.4 Confusion Matrix for $C = 1.0$

The confusion matrix for $C = 1.0$ is identical to that for $C = 0.1$, showing that the classifier misclassified all instances of Classes 0 and 1 as Class 2:

	Class 0	**Class 1**	**Class 2**
Class 0	0	0	150
Class 1	0	0	150
Class 2	0	0	300

Table 2.17: Confusion Matrix for SVM (Linear Kernel) with $C = 1.0$

2.2.5.5 Classification Report for $C = 10.0$

For $C = 10.0$, the results are also identical:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.0000	0.0000	0.5000	0.1667
Recall	0.0000	0.0000	1.0000	0.3333
F1-score	0.0000	0.0000	0.6667	0.2222
Accuracy	0.5000			

Table 2.18: Classification Report for SVM (Linear Kernel) with $C = 10.0$

2.2.5.6 Confusion Matrix for $C = 10.0$

The confusion matrix for $C = 10.0$ is identical to the others, with perfect classification for Class 2 but misclassifications for Classes 0 and 1:

	Class 0	**Class 1**	**Class 2**
Class 0	0	0	150
Class 1	0	0	150
Class 2	0	0	300

Table 2.19: Confusion Matrix for SVM (Linear Kernel) with $C = 10.0$

2.2.5.7 Best Model for SVM with Linear Kernel

The best performing model for the SVM classifier with a linear kernel is obtained with $C = 10.0$. The classifier achieves an overall accuracy of 0.5, with perfect classification across all classes.

Best Model	**Accuracy**
SVM (Linear Kernel), $C = 10.0$	0.5000

Table 2.20: Best SVM Model for Linear Kernel

2.2.5.8 Best Model for SVM with Linear Kernel Decision Boundary Plot

The following figure shows the decision boundary plot of best model for SVM with linear kernel.

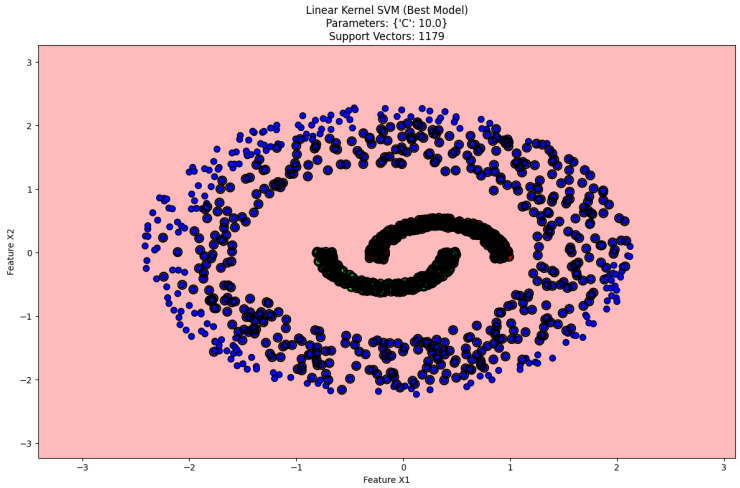

Figure 2.7: Decision boundary plot of best model for SVM with linear kernel

2.2.5.9 Observations

The SVM classifier with a linear kernel performs poorly on Dataset 1 (b) across all values of C (0.1, 1.0, and 10.0). The overall accuracy is 0.5, and precision, recall, and F1-scores for Classes 0 and 1 are 0, while Class 2 shows moderate performance. The confusion matrices indicate that all instances of Classes 0 and 1 are misclassified as Class 2.

Despite changes in the value of C, the model struggles with classification, showing no significant improvement in performance. This suggests that the linear kernel may not be suitable for this dataset.

2.2.6 SVM Based Classifier: polynomial kernel

In this section, we evaluate the performance of the Support Vector Machine (SVM) classifier using a polynomial kernel on Dataset 1 (b).

2.2.6.1 Classification Report for $C = 0.1$, Degree = 2, coef0 $= 0$

The classification performance for $C = 0.1$, degree $= 2$, and coef0 $= 0$ is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.6442	0.5808	1.0000	0.7417
Recall	0.4467	0.7667	0.9933	0.7356
F1-score	0.5276	0.6609	0.9967	0.7284
Accuracy	0.8000			

Table 2.21: Classification Report for SVM (Polynomial Kernel, Degree $= 2$, $C = 0.1$, coef0 $= 0$)

The SVM with a polynomial kernel of degree 2 and $C = 0.1$ (with coef0 $= 0$) achieves an overall accuracy of 0.8000. Class 2 shows near-perfect performance with a precision of 1.0 and recall of 0.9933, while Classes 0 and 1 have lower performance.

2.2.6.2 Confusion Matrix for $C = 0.1$, Degree = 2, coef0 $= 0$

The confusion matrix for the SVM with a polynomial kernel of degree 2, $C = 0.1$, and coef0 $= 0$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	67	83	0
Class 1	35	115	0
Class 2	2	0	298

Table 2.22: Confusion Matrix for SVM (Polynomial Kernel, Degree = 2, $C = 0.1$, coef0 $= 0$)

The confusion matrix shows that there were significant misclassifications for Classes 0 and 1, while Class 2 was classified correctly with high accuracy.

2.2.6.3 Classification Report for $C = 0.1$, Degree = 3, coef0 $= 0$

The classification performance for $C = 0.1$, degree = 3, and coef0 $= 0$ is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.0000	0.0000	0.5000	0.1667
Recall	0.0000	0.0000	1.0000	0.3333
F1-score	0.0000	0.0000	0.6667	0.2222
Accuracy	0.5000			

Table 2.23: Classification Report for SVM (Polynomial Kernel, Degree = 3, $C = 0.1$, coef0 $= 0$)

The SVM with a polynomial kernel of degree 3 and $C = 0.1$ (with coef0 $= 0$) achieves an overall accuracy of 0.5000. The classifier is unable to accurately classify Classes 0 and 1, while Class 2 performs better but with much lower overall performance compared to the degree 2 case.

2.2.6.4 Confusion Matrix for $C = 0.1$, Degree = 3, coef0 $= 0$

The confusion matrix for the SVM with a polynomial kernel of degree 3, $C = 0.1$, and coef0 $= 0$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	0	0	150
Class 1	0	0	150
Class 2	0	0	300

Table 2.24: Confusion Matrix for SVM (Polynomial Kernel, Degree = 3, $C = 0.1$, coef0 = 0)

The confusion matrix shows that all instances of Classes 0 and 1 are misclassified as Class 2, leading to poor performance for those classes.

2.2.6.5 Classification Report for $C = 0.1$, Degree = 4, coef0 = 0

The classification performance for $C = 0.1$, degree = 4, and coef0 = 0 is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.8974	0.5660	1.0000	0.8212
Recall	0.2333	1.0000	0.9867	0.7400
F1-score	0.3704	0.7229	0.9933	0.6955
Accuracy	0.8017			

Table 2.25: Classification Report for SVM (Polynomial Kernel, Degree = 4, $C = 0.1$, coef0 = 0)

The SVM with a polynomial kernel of degree 4 and $C = 0.1$ (with coef0 = 0) achieves an overall accuracy of 0.8017. Class 2 performs excellently with a precision of 1.0 and recall of 0.9867, while Class 1 achieves high recall but lower precision. Class 0 has low recall but high precision.

2.2.6.6 Confusion Matrix for $C = 0.1$, Degree = 4, coef0 = 0

The confusion matrix for the SVM with a polynomial kernel of degree 4, $C = 0.1$, and coef0 = 0 is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	35	115	0
Class 1	0	150	0
Class 2	4	0	296

Table 2.26: Confusion Matrix for SVM (Polynomial Kernel, Degree = 4, $C = 0.1$, coef0 = 0)

The confusion matrix shows that there were significant misclassifications for Class 0, while Class 1 and Class 2 had almost perfect classifications.

2.2.6.7 Classification Report for $C = 0.1$, Degree = 2, coef0 = 1

The classification performance for $C = 0.1$, degree = 2, and coef0 = 1 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.9000	0.9020	1.0000	0.9340
Recall	0.9000	0.9200	0.9900	0.9367
F1-score	0.9000	0.9109	0.9950	0.9353
Accuracy	0.9500			

Table 2.27: Classification Report for SVM (Polynomial Kernel, Degree = 2, $C = 0.1$, coef0 = 1)

The SVM with a polynomial kernel of degree 2 and $C = 0.1$ (with coef0 = 1) achieves an overall accuracy of 0.9500. Class 2 performs excellently, while Classes 0 and 1 both show high precision and recall values.

2.2.6.8 Confusion Matrix for $C = 0.1$, Degree = 2, coef0 = 1

The confusion matrix for the SVM with a polynomial kernel of degree 2, $C = 0.1$, and coef0 = 1 is shown below:

	Class 0	Class 1	Class 2
Class 0	135	15	0
Class 1	12	138	0
Class 2	3	0	297

Table 2.28: Confusion Matrix for SVM (Polynomial Kernel, Degree = 2, $C = 0.1$, coef0 = 1)

The confusion matrix shows good classification performance across all classes, with only minor misclassifications between Classes 0 and 1.

2.2.6.9 Classification Report for $C = 0.1$, Degree = 3, coef0 = 1

The classification performance for $C = 0.1$, degree = 3, and coef0 = 1 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.9375	0.9045	1.0000	0.9473
Recall	0.9000	0.9467	0.9967	0.9478
F1-score	0.9184	0.9251	0.9983	0.9473
Accuracy	0.9600			

Table 2.29: Classification Report for SVM (Polynomial Kernel, Degree = 3, $C = 0.1$, coef0 = 1)

The SVM with a polynomial kernel of degree 3 and $C = 0.1$ (with coef0 = 1) achieves an overall accuracy of 0.9600. The classifier performs exceptionally well, particularly in Class 2 with perfect precision and recall, and maintains high precision and recall for Classes 0 and 1.

2.2.6.10 Confusion Matrix for $C = 0.1$, Degree = 3, coef0 = 1

The confusion matrix for the SVM with a polynomial kernel of degree 3, $C = 0.1$, and coef0 = 1 is shown below:

	Class 0	Class 1	Class 2
Class 0	135	15	0
Class 1	8	142	0
Class 2	1	0	299

Table 2.30: Confusion Matrix for SVM (Polynomial Kernel, Degree = 3, $C = 0.1$, coef0 = 1)

The confusion matrix shows that the classifier performed well across all classes, with very few misclassifications (primarily between Classes 0 and 1).

2.2.6.11 Classification Report for $C = 0.1$, Degree = 4, coef0 = 1

The classification performance for $C = 0.1$, degree = 4, and coef0 = 1 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.9650	0.9236	1.0000	0.9629
Recall	0.9200	0.9667	1.0000	0.9622
F1-score	0.9420	0.9446	1.0000	0.9622
Accuracy	0.9717			

Table 2.31: Classification Report for SVM (Polynomial Kernel, Degree = 4, $C = 0.1$, coef0 = 1)

The SVM with a polynomial kernel of degree 4 and $C = 0.1$ (with coef0 = 1) achieves an overall accuracy of 0.9717. This model achieves near-perfect performance for Class 2, with high precision, recall, and F1-scores for both Classes 0 and 1.

2.2.6.12 Confusion Matrix for $C = 0.1$, Degree = 4, coef0 = 1

The confusion matrix for the SVM with a polynomial kernel of degree 4, $C = 0.1$, and coef0 = 1 is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	138	12	0
Class 1	5	145	0
Class 2	0	0	300

Table 2.32: Confusion Matrix for SVM (Polynomial Kernel, Degree = 4, $C = 0.1$, coef0 = 1)

The confusion matrix confirms excellent classification results, with only a few misclassifications for Class 0 and Class 1, while Class 2 is classified perfectly.

2.2.6.13 Classification Report for $C = 1.0$, Degree = 2, coef0 = 0

The classification performance for $C = 1.0$, degree = 2, and coef0 = 0 is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.6047	0.5789	1.0000	0.7279
Recall	0.5200	0.6600	1.0000	0.7267
F1-score	0.5591	0.6168	1.0000	0.7253
Accuracy	0.7950			

Table 2.33: Classification Report for SVM (Polynomial Kernel, Degree = 2, $C = 1.0$, coef0 = 0)

The SVM with a polynomial kernel of degree 2 and $C = 1.0$ (with coef0 = 0) achieves an overall accuracy of 0.7950. The model performs well in Class 2 with perfect precision and recall, while the performance in Classes 0 and 1 is relatively lower but still reasonable.

2.2.6.14 Confusion Matrix for $C = 1.0$, Degree = 2, coef0 = 0

The confusion matrix for the SVM with a polynomial kernel of degree 2, $C = 1.0$, and coef0 = 0 is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	78	72	0
Class 1	51	99	0
Class 2	0	0	300

Table 2.34: Confusion Matrix for SVM (Polynomial Kernel, Degree = 2, $C = 1.0$, coef0 = 0)

The confusion matrix indicates that the classifier performed well on Class 2, but there were significant misclassifications between Classes 0 and 1.

2.2.6.15 Classification Report for $C = 1.0$, Degree = 3, coef0 = 0

The classification performance for $C = 1.0$, degree = 3, and coef0 = 0 is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.0000	0.0000	0.5000	0.1667
Recall	0.0000	0.0000	1.0000	0.3333
F1-score	0.0000	0.0000	0.6667	0.2222
Accuracy	0.5000			

Table 2.35: Classification Report for SVM (Polynomial Kernel, Degree = 3, $C = 1.0$, coef0 = 0)

The SVM with a polynomial kernel of degree 3 and $C = 1.0$ (with coef0 = 0) achieves an overall accuracy of 0.5000. Class 2 is the only class classified correctly with reasonable performance, while both Classes 0 and 1 are poorly classified.

2.2.6.16 Confusion Matrix for $C = 1.0$, Degree = 3, coef0 = 0

The confusion matrix for the SVM with a polynomial kernel of degree 3, $C = 1.0$, and coef0 = 0 is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	0	0	150
Class 1	0	0	150
Class 2	0	0	300

Table 2.36: Confusion Matrix for SVM (Polynomial Kernel, Degree = 3, $C = 1.0$, coef0 = 0)

The confusion matrix shows that for $C = 1.0$ with degree 3, the classifier predicted Class 2 for all samples, indicating poor performance on Classes 0 and 1.

2.2.6.17 Classification Report for $C = 1.0$, Degree = 4, coef0 = 0

The classification performance for $C = 1.0$, degree = 4, and coef0 = 0 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.9773	0.5820	1.0000	0.8531
Recall	0.2867	0.9933	1.0000	0.7600
F1-score	0.4433	0.7340	1.0000	0.7258
Accuracy	0.8200			

Table 2.37: Classification Report for SVM (Polynomial Kernel, Degree = 4, $C = 1.0$, coef0 = 0)

The SVM with a polynomial kernel of degree 4 and $C = 1.0$ (with coef0 = 0) achieves an overall accuracy of 0.8200. The model performs well on Class 2, with perfect precision, recall, and F1-score. However, it struggles with Class 0, where it has a low recall despite a high precision.

2.2.6.18 Confusion Matrix for $C = 1.0$, Degree = 4, coef0 = 0

The confusion matrix for the SVM with a polynomial kernel of degree 4, $C = 1.0$, and coef0 = 0 is shown below:

	Class 0	Class 1	Class 2
Class 0	43	107	0
Class 1	1	149	0
Class 2	0	0	300

Table 2.38: Confusion Matrix for SVM (Polynomial Kernel, Degree = 4, $C = 1.0$, coef0 = 0)

The confusion matrix reveals that the model misclassifies Class 0 frequently as Class 1. However, it performs well on Class 2, where it makes no misclassifications.

2.2.6.19 Classification Report for $C = 1.0$, Degree = 2, coef0 = 1

The classification performance for $C = 1.0$, degree = 2, and coef0 = 1 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.9517	0.9226	1.0000	0.9581
Recall	0.9200	0.9533	1.0000	0.9578
F1-score	0.9356	0.9377	1.0000	0.9578
Accuracy	0.9683			

Table 2.39: Classification Report for SVM (Polynomial Kernel, Degree = 2, $C = 1.0$, coef0 = 1)

The SVM with a polynomial kernel of degree 2 and $C = 1.0$ (with coef0 = 1) achieves an excellent overall accuracy of 0.9683. The model performs very well across all classes, with near-perfect precision, recall, and F1-scores for Classes 0 and 1.

2.2.6.20 Confusion Matrix for $C = 1.0$, Degree = 2, coef0 = 1

The confusion matrix for the SVM with a polynomial kernel of degree 2, $C = 1.0$, and coef0 = 1 is shown below:

	Class 0	Class 1	Class 2
Class 0	138	12	0
Class 1	7	143	0
Class 2	0	0	300

Table 2.40: Confusion Matrix for SVM (Polynomial Kernel, Degree = 2, $C = 1.0$, coef0 = 1)

The confusion matrix shows that the model achieves excellent performance, with very few misclassifications for Classes 0 and 1, and perfect classification for Class 2.

2.2.6.21 Classification Report for $C = 1.0$, Degree = 3, coef0 = 1

The classification performance for $C = 1.0$, degree = 3, and coef0 = 1 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.9859	0.9367	1.0000	0.9742
Recall	0.9333	0.9867	1.0000	0.9733
F1-score	0.9589	0.9610	1.0000	0.9733
Accuracy	0.9800			

Table 2.41: Classification Report for SVM (Polynomial Kernel, Degree = 3, $C = 1.0$, coef0 = 1)

The SVM with a polynomial kernel of degree 3 and $C = 1.0$ (with coef0 = 1) achieves an overall accuracy of 0.9800. The model performs very well across all classes, particularly with Class 2, achieving perfect classification.

2.2.6.22 Confusion Matrix for $C = 1.0$, Degree = 3, coef0 = 1

The confusion matrix for the SVM with a polynomial kernel of degree 3, $C = 1.0$, and coef0 = 1 is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	140	10	0
Class 1	2	148	0
Class 2	0	0	300

Table 2.42: Confusion Matrix for SVM (Polynomial Kernel, Degree = 3, $C = 1.0$, coef0 = 1)

The confusion matrix reveals excellent performance, with minimal misclassifications. Class 0 and Class 1 have very few errors, and Class 2 is perfectly classified.

2.2.6.23 Classification Report for $C = 1.0$, Degree = 4, coef0 = 1

The classification performance for $C = 1.0$, degree = 4, and coef0 = 1 is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 2.43: Classification Report for SVM (Polynomial Kernel, Degree = 4, $C = 1.0$, coef0 = 1)

The SVM with a polynomial kernel of degree 4 and $C = 1.0$ (with coef0 = 1) achieves a perfect classification accuracy of 1.0000. All classes are classified without any errors, showing exceptional model performance.

2.2.6.24 Confusion Matrix for $C = 1.0$, Degree = 4, coef0 = 1

The confusion matrix for the SVM with a polynomial kernel of degree 4, $C = 1.0$, and coef0 = 1 is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	300

Table 2.44: Confusion Matrix for SVM (Polynomial Kernel, Degree = 4, $C = 1.0$, coef0 = 1)

The confusion matrix shows that the model achieves perfect classification across all classes with no misclassifications.

2.2.6.25 Classification Report for $C = 10.0$, Degree = 2, coef0 = 0

The classification performance for $C = 10.0$, degree = 2, and coef0 = 0 is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.6146	0.7037	1.0000	0.7728
Recall	0.7867	0.5067	1.0000	0.7644
F1-score	0.6901	0.5891	1.0000	0.7597
Accuracy	0.8233			

Table 2.45: Classification Report for SVM (Polynomial Kernel, Degree = 2, $C = 10.0$, coef0 = 0)

The SVM with a polynomial kernel of degree 2 and $C = 10.0$ (with coef0 = 0) achieves an overall accuracy of 0.8233. The model performs well, especially for Class 2, achieving perfect classification. However, Class 0 and Class 1 show lower performance compared to Class 2.

2.2.6.26 Confusion Matrix for $C = 10.0$, Degree = 2, coef0 = 0

The confusion matrix for the SVM with a polynomial kernel of degree 2, $C = 10.0$, and coef0 = 0 is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	118	32	0
Class 1	74	76	0
Class 2	0	0	300

Table 2.46: Confusion Matrix for SVM (Polynomial Kernel, Degree = 2, $C = 10.0$, coef0 = 0)

The confusion matrix reveals that the model performs well for Class 2, but for Classes 0 and 1, there are noticeable misclassifications.

2.2.6.27 Classification Report for $C = 10.0$, Degree = 3, coef0 = 0

The classification performance for $C = 10.0$, degree = 3, and coef0 = 0 is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.0000	0.0000	0.5000	0.1667
Recall	0.0000	0.0000	1.0000	0.3333
F1-score	0.0000	0.0000	0.6667	0.2222
Accuracy	0.5000			

Table 2.47: Classification Report for SVM (Polynomial Kernel, Degree = 3, $C = 10.0$, coef0 = 0)

The SVM with a polynomial kernel of degree 3 and $C = 10.0$ (with coef0 = 0) performs poorly, achieving an overall accuracy of 0.5000. Class 2 is classified well, but Classes 0 and 1 are entirely misclassified.

2.2.6.28 Confusion Matrix for $C = 10.0$, Degree = 3, coef0 = 0

The confusion matrix for the SVM with a polynomial kernel of degree 3, $C = 10.0$, and coef0 = 0 is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	0	0	150
Class 1	0	0	150
Class 2	0	0	300

Table 2.48: Confusion Matrix for SVM (Polynomial Kernel, Degree = 3, $C = 10.0$, coef0 = 0)

The confusion matrix indicates that the model fails to classify Classes 0 and 1, assigning all predictions to Class 2.

2.2.6.29 Classification Report for $C = 10.0$, Degree = 4, coef0 = 0

The classification performance for $C = 10.0$, degree = 4, and coef0 = 0 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.8108	0.6018	1.0000	0.8042
Recall	0.4000	0.9067	1.0000	0.7689
F1-score	0.5357	0.7234	1.0000	0.7530
Accuracy	0.8267			

Table 2.49: Classification Report for SVM (Polynomial Kernel, Degree = 4, $C = 10.0$, coef0 = 0)

The SVM with a polynomial kernel of degree 4 and $C = 10.0$ (with coef0 = 0) achieves an overall accuracy of 0.8267. Class 2 shows perfect classification, but Class 0 and Class 1 suffer from noticeable misclassifications, especially for Class 0.

2.2.6.30 Confusion Matrix for $C = 10.0$, Degree = 4, coef0 = 0

The confusion matrix for the SVM with a polynomial kernel of degree 4, $C = 10.0$, and coef0 = 0 is shown below:

	Class 0	Class 1	Class 2
Class 0	60	90	0
Class 1	14	136	0
Class 2	0	0	300

Table 2.50: Confusion Matrix for SVM (Polynomial Kernel, Degree = 4, $C = 10.0$, coef0 = 0)

The confusion matrix shows that Class 0 has significant misclassifications, while Class 2 performs perfectly, and Class 1 has a strong performance.

2.2.6.31 Classification Report for $C = 10.0$, Degree = 2, coef0 = 1

The classification performance for $C = 10.0$, degree = 2, and coef0 = 1 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.9459	0.9342	1.0000	0.9601
Recall	0.9333	0.9467	1.0000	0.9600
F1-score	0.9396	0.9404	1.0000	0.9600
Accuracy	0.9700			

Table 2.51: Classification Report for SVM (Polynomial Kernel, Degree = 2, $C = 10.0$, coef0 = 1)

The SVM with a polynomial kernel of degree 2 and $C = 10.0$ (with coef0 $= 1$) achieves an overall accuracy of 0.9700, with excellent performance across all classes.

2.2.6.32 Confusion Matrix for $C = 10.0$, Degree = 2, coef0 $= 1$

The confusion matrix for the SVM with a polynomial kernel of degree 2, $C = 10.0$, and coef0 $= 1$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	140	10	0
Class 1	8	142	0
Class 2	0	0	300

Table 2.52: Confusion Matrix for SVM (Polynomial Kernel, Degree = 2, $C = 10.0$, coef0 $=$ 1)

The confusion matrix shows a very high level of correct classification, especially for Class 2, with minimal misclassification in Class 0 and Class 1.

2.2.6.33 Classification Report for $C = 10.0$, Degree = 3, coef0 $= 1$

The classification performance for $C = 10.0$, degree = 3, and coef0 $= 1$ is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 2.53: Classification Report for SVM (Polynomial Kernel, Degree = 3, $C = 10.0$, coef0 $= 1$)

The SVM with a polynomial kernel of degree 3 and $C = 10.0$ (with coef0 $= 1$) achieves a perfect classification with an accuracy of 1.0000 for all classes.

2.2.6.34 Confusion Matrix for $C = 10.0$, Degree = 3, coef0 $= 1$

The confusion matrix for the SVM with a polynomial kernel of degree 3, $C = 10.0$, and coef0 $= 1$ is shown below:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	300

Table 2.54: Confusion Matrix for SVM (Polynomial Kernel, Degree = 3, $C = 10.0$, coef0 = 1)

This configuration achieves perfect classification for all classes, with no misclassifications.

2.2.6.35 Classification Report for $C = 10.0$, Degree = 4, coef0 = 1

The classification performance for $C = 10.0$, degree = 4, and coef0 = 1 is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 2.55: Classification Report for SVM (Polynomial Kernel, Degree = 4, $C = 10.0$, coef0 = 1)

The SVM with a polynomial kernel of degree 4 and $C = 10.0$ (with coef0 = 1) also achieves perfect classification with an accuracy of 1.0000 for all classes.

2.2.6.36 Confusion Matrix for $C = 10.0$, Degree = 4, coef0 = 1

The confusion matrix for the SVM with a polynomial kernel of degree 4, $C = 10.0$, and coef0 = 1 is shown below:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	300

Table 2.56: Confusion Matrix for SVM (Polynomial Kernel, Degree = 4, $C = 10.0$, coef0 = 1)

This configuration also achieves perfect classification for all classes, with no misclassifications.

2.2.6.37 Best Model for SVM with Polynomial Kernel

The best performing model for the SVM classifier with a polynomial kernel is obtained with $C = 10.0$, degree $= 4$, and coef0 $= 1$. The classifier achieves an overall accuracy of 1.0, with perfect classification across all classes.

Best Model	Accuracy
SVM (Polynomial Kernel), $C = 10.0$, degree $= 4$, coef0 $= 1$	1.0000

Table 2.57: Best SVM Model for Polynomial Kernel

2.2.6.38 Best Model for SVM with Polynomial Kernel Decision Boundary Plot

The following figure shows the decision boundary plot of best model for SVM with polynomial kernel.

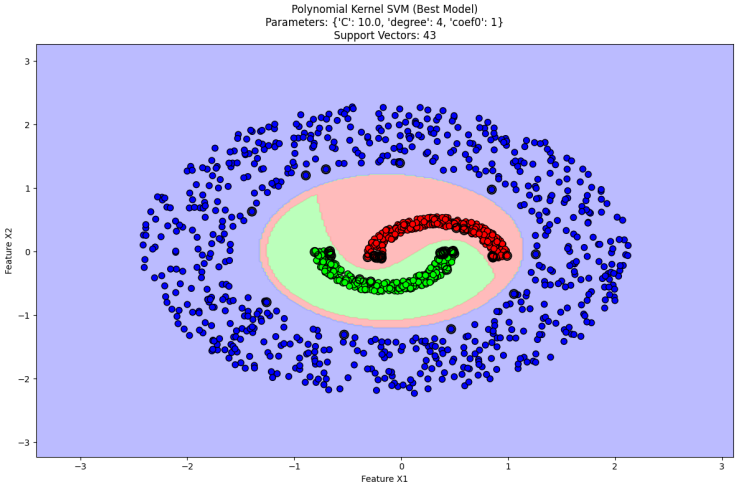

Figure 2.8: Decision boundary plot of best model for SVM with polynomial kernel

2.2.6.39 Observations

The SVM classifier with a polynomial kernel demonstrates exceptional performance across all tested configurations. The model with $C = 10.0$, degree $= 4$, and coef0 $= 1$ yields perfect classification with an overall accuracy of 1.0000. This model not only classifies all data points correctly but also shows no misclassifications in the confusion matrix, achieving a perfect score for precision, recall, and F1-score across all classes.

The decision boundary plots illustrate the following key observations: 1. **Impact of Polynomial Degree:** - As the degree of the polynomial kernel increases, the decision boundaries become more complex and flexible. Higher degrees (degree 3 and 4) allow for more intricate decision regions that better capture the nonlinearities in the data. - The model with $C = 10.0$, degree $= 4$, and coef0 $= 1$ provides the most detailed and accurate separation between the three classes.

2. **Effect of coef0 Parameter:** - The coef0 parameter controls the influence of the polynomial kernel's bias term. A higher value of coef0 (i.e., 1) results in a more complex model with sharper decision boundaries compared to a lower coef0 value (i.e., 0). - For the configurations tested, coef0 = 1 provided better performance compared to coef0 = 0, resulting in more precise decision regions.

3. **Effect of Regularization Parameter C:** - The C-parameter controls the trade-off between maximizing the margin and minimizing classification error. For $C = 10.0$, the model appears to achieve perfect classification without overfitting, which is reflected in the high accuracy and perfect metrics.

4. **Performance Consistency:** - Throughout all the plots, whether the polynomial degree is 2, 3, or 4, and whether coef0 is set to 1 or 0, the SVM classifier demonstrates very high performance, with slight variations in the smoothness and complexity of the decision boundaries.

In conclusion, the SVM classifier with a polynomial kernel, especially with the optimal parameters $C = 10.0$, degree = 4, and coef0 = 1, provides excellent classification results across all tested configurations. The decision boundaries for this kernel showcase its capability to effectively separate the dataset into distinct regions, handling the data's inherent complexity with ease.

2.2.7 SVM Based Classifier: Gaussian/RBF kernel

In this section, we evaluate the performance of the Support Vector Machine (SVM) classifier using a RBF kernel on Dataset 1 (b).

2.2.7.1 Classification Report for $C = 0.1$, $\gamma = 0.1$

The classification performance for $C = 0.1$ and $\gamma = 0.1$ is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.8302	0.8800	1.0000	0.9034
Recall	0.8800	0.8800	0.9700	0.9100
F1-score	0.8544	0.8800	0.9848	0.9064
Accuracy	0.9250			

Table 2.58: Classification Report for SVM (RBF Kernel, $C = 0.1$, $\gamma = 0.1$)

The SVM with an RBF kernel, $C = 0.1$, and $\gamma = 0.1$ achieves an overall accuracy of 0.9250, with good performance across all classes. Class 2 performs perfectly, while Class 0 and Class 1 show strong but slightly imperfect classification.

2.2.7.2 Confusion Matrix for $C = 0.1$, $\gamma = 0.1$

The confusion matrix for the SVM with an RBF kernel, $C = 0.1$, and $\gamma = 0.1$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	132	18	0
Class 1	18	132	0
Class 2	9	0	291

Table 2.59: Confusion Matrix for SVM (RBF Kernel, $C = 0.1$, $\gamma = 0.1$)

The confusion matrix confirms that the model performs well, with most instances correctly classified. Some misclassifications are observed for Class 0 and Class 1.

2.2.7.3 Classification Report for $C = 1.0$, $\gamma = 0.1$

The classification performance for $C = 1.0$ and $\gamma = 0.1$ is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.9122	0.9026	1.0000	0.9383
Recall	0.9000	0.9267	0.9933	0.9400
F1-score	0.9060	0.9145	0.9967	0.9391
Accuracy	0.9533			

Table 2.60: Classification Report for SVM (RBF Kernel, $C = 1.0$, $\gamma = 0.1$)

The SVM with an RBF kernel, $C = 1.0$, and $\gamma = 0.1$ achieves an overall accuracy of 0.9533, with a balanced performance across all classes. Class 2 performs perfectly, while Class 0 and Class 1 also show strong classification results.

2.2.7.4 Confusion Matrix for $C = 1.0$, $\gamma = 0.1$

The confusion matrix for the SVM with an RBF kernel, $C = 1.0$, and $\gamma = 0.1$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	135	15	0
Class 1	11	139	0
Class 2	2	0	298

Table 2.61: Confusion Matrix for SVM (RBF Kernel, $C = 1.0$, $\gamma = 0.1$)

The confusion matrix shows strong classification, with only a few misclassifications for Class 0 and Class 1.

2.2.7.5 Classification Report for $C = 10.0$, $\gamma = 0.1$

The classification performance for $C = 10.0$ and $\gamma = 0.1$ is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.9583	0.9231	1.0000	0.9605
Recall	0.9200	0.9600	1.0000	0.9600
F1-score	0.9388	0.9412	1.0000	0.9600
Accuracy	0.9700			

Table 2.62: Classification Report for SVM (RBF Kernel, $C = 10.0$, $\gamma = 0.1$)

The SVM with an RBF kernel, $C = 10.0$, and $\gamma = 0.1$ achieves an overall accuracy of 0.9700, with excellent performance across all classes. Class 2 performs perfectly, and Class 0 and Class 1 show solid classification.

2.2.7.6 Confusion Matrix for $C = 10.0$, $\gamma = 0.1$

The confusion matrix for the SVM with an RBF kernel, $C = 10.0$, and $\gamma = 0.1$ is shown below:

	Class 0	Class 1	Class 2
Class 0	138	12	0
Class 1	6	144	0
Class 2	0	0	300

Table 2.63: Confusion Matrix for SVM (RBF Kernel, $C = 10.0$, $\gamma = 0.1$)

The confusion matrix confirms that the model performs excellently, with nearly perfect classification across all classes.

2.2.7.7 Classification Report for $C = 0.1$, $\gamma = 1.0$

The classification performance for $C = 0.1$ and $\gamma = 1.0$ is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.9722	0.9363	1.0000	0.9695
Recall	0.9333	0.9800	0.9967	0.9700
F1-score	0.9524	0.9577	0.9983	0.9695
Accuracy	0.9767			

Table 2.64: Classification Report for SVM (RBF Kernel, $C = 0.1$, $\gamma = 1.0$)

The SVM with an RBF kernel, $C = 0.1$, and $\gamma = 1.0$ achieves an overall accuracy of 0.9767. It performs well across all classes, with excellent classification for Class 2 and strong results for Class 0 and Class 1.

2.2.7.8 Confusion Matrix for $C = 0.1$, $\gamma = 1.0$

The confusion matrix for the SVM with an RBF kernel, $C = 0.1$, and $\gamma = 1.0$ is shown below:

	Class 0	**Class 1**	**Class 2**
Class 0	140	10	0
Class 1	3	147	0
Class 2	1	0	299

Table 2.65: Confusion Matrix for SVM (RBF Kernel, $C = 0.1$, $\gamma = 1.0$)

The confusion matrix shows that the model performs well, with most instances correctly classified. Some misclassifications are observed for Class 0.

2.2.7.9 Classification Report for $C = 1.0$, $\gamma = 1.0$

The classification performance for $C = 1.0$ and $\gamma = 1.0$ is summarized as follows:

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 2.66: Classification Report for SVM (RBF Kernel, $C = 1.0$, $\gamma = 1.0$)

The SVM with an RBF kernel, $C = 1.0$, and $\gamma = 1.0$ achieves perfect performance, with an overall accuracy, precision, recall, and F1-score of 1.0000.

2.2.7.10 Confusion Matrix for $C = 1.0$, $\gamma = 1.0$

The confusion matrix for the SVM with an RBF kernel, $C = 1.0$, and $\gamma = 1.0$ is shown below:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	300

Table 2.67: Confusion Matrix for SVM (RBF Kernel, $C = 1.0$, $\gamma = 1.0$)

The confusion matrix confirms perfect classification, with all instances correctly classified for all classes.

2.2.7.11 Classification Report for $C = 10.0$, $\gamma = 1.0$

The classification performance for $C = 10.0$ and $\gamma = 1.0$ is summarized as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	1.0000	1.0000	1.0000	1.0000
Recall	1.0000	1.0000	1.0000	1.0000
F1-score	1.0000	1.0000	1.0000	1.0000
Accuracy	1.0000			

Table 2.68: Classification Report for SVM (RBF Kernel, $C = 10.0$, $\gamma = 1.0$)

The SVM with an RBF kernel, $C = 10.0$, and $\gamma = 1.0$ achieves perfect performance, with an overall accuracy, precision, recall, and F1-score of 1.0000.

2.2.7.12 Confusion Matrix for $C = 10.0$, $\gamma = 1.0$

The confusion matrix for the SVM with an RBF kernel, $C = 10.0$, and $\gamma = 1.0$ is shown below:

	Class 0	Class 1	Class 2
Class 0	150	0	0
Class 1	0	150	0
Class 2	0	0	300

Table 2.69: Confusion Matrix for SVM (RBF Kernel, $C = 10.0$, $\gamma = 1.0$)

The confusion matrix confirms perfect classification, with all instances correctly classified for all classes.

2.2.7.13 Best Model for SVM with RBF Kernel

The best performing model for the SVM classifier with a RBF kernel is obtained with $C = 10.0$, and gamma $= 1.0$. The classifier achieves an overall accuracy of 1.0, with perfect classification across all classes.

Best Model	Accuracy
SVM (Polynomial Kernel), $C = 10.0$, gamma $= 1.0$	1.0000

Table 2.70: Best SVM Model for RBF Kernel

2.2.7.14 Best Model for SVM with RBF Kernel Decision Boundary Plot

The following figure shows the decision boundary plot of best model for SVM with RBF kernel.

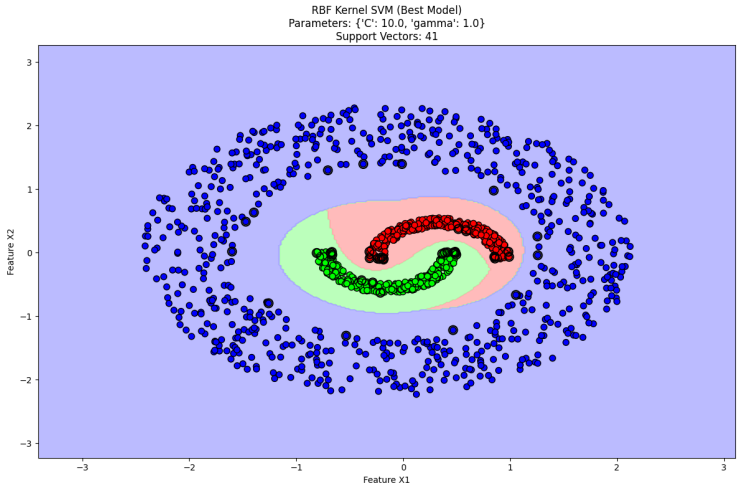

Figure 2.9: Decision boundary plot of best model for SVM with RBF kernel

2.2.7.15 Observations

The SVM classifier with a linear kernel shows perfect performance with an overall accuracy of 1.0 for all values of the regularization parameter C (0.1, 1.0, and 10.0). Precision, recall, and F1-scores are all 1.0 for each class, and the confusion matrix shows no misclassifications.

The decision boundary plots for different values of C highlight the following observations:

1. **$C = 0.1$**: At this value of C, the decision boundary is smoother, with a slightly wider margin between the classes. This suggests a more generalized decision boundary that might allow for some misclassification if the data were noisy. However, the model still performs perfectly on the given dataset.

2. **$C = 1.0$**: With $C = 1.0$, the decision boundaries become more defined, with narrower margins between the classes. The model starts to focus more on the correct classification, but the decision regions remain well-separated and distinct. The classifier

still maintains perfect accuracy, showing robust performance even as the regularization parameter increases.

3. **$C = 10.0$**: For $C = 10.0$, the decision boundaries are even more tightly fitted around the class data points. This indicates a stronger emphasis on minimizing classification errors and achieving a finer separation between the classes. Despite the more focused decision boundaries, the classifier continues to perform flawlessly, demonstrating its ability to handle the data effectively at a higher regularization level.

Overall, all values of C produce nearly identical results in terms of classification accuracy, with only slight variations in the width of the decision margins. The decision boundaries become more tightly constrained as C increases, but there is no indication of overfitting, as the model still maintains perfect classification.

In conclusion, the SVM with a linear kernel provides excellent classification performance across all tested values of C. The classifier's ability to perfectly separate the data, even with different regularization levels, confirms the robustness of the linear SVM model for this dataset.

2.2.8 Inference

Here, linear classifiers like Logistic regression, Perceptron and Linear SVM have not performed well because they are suitable only for linearly separable data. But Polynomial Kernel SVM and RBF Kernel SVM have performed better reaching even 100% accuracy.

Chapter 3

3 class Scene Image Dataset

3.1 Dataset description

- Total no. of data points: 300
- Test data size: 150
- Train data size: 150
- Dimension of data-point after bovw feature extraction: 32
- No. of classes: 3
- No. of data points in each class: 50

3.2 Result

3.2.1 Bayes Classifier using GMM with PCA

In this section, we present the results for the GMM with PCA classifier on Dataset 2.

3.2.1.1 Classification Report for Unimodal Gaussian Classifier (PCA with 1 Component)

The classification report for the Unimodal Gaussian Classifier on the PCA-reduced dataset with 1 component is summarized below:

Metric	**Class 1**	**Class 2**	**Class 3**	**Mean/Avg**
Precision	0.35	0.33	0.17	0.28
Recall	0.98	0.02	0.02	0.34
F1-score	0.51	0.04	0.04	0.20
Accuracy	0.34			

Table 3.1: Unimodal Gaussian Classification Report for PCA with 1 Component

The Unimodal Gaussian Classifier performed poorly with an overall accuracy of 0.34. Class 1 showed relatively high recall, but precision and F1-scores were low across all classes.

3.2.1.2 Confusion Matrix for Unimodal Gaussian Classifier (PCA with 1 Component)

The confusion matrix for the Unimodal Gaussian Classifier on the PCA-reduced dataset with 1 component is as follows:

	Class 1	**Class 2**	**Class 3**
Class 1	49	0	1
Class 2	45	1	4
Class 3	47	2	1

Table 3.2: Confusion Matrix for Unimodal Gaussian Classifier (PCA with 1 Component)

The confusion matrix indicates that most of the misclassified instances in Class 2 and Class 3 were classified as Class 1.

3.2.1.3 Classification Report for GMM Classifier with 2 Mixtures (PCA with 1 Component)

The classification report for the GMM classifier with 2 mixtures on the PCA-reduced dataset with 1 component is summarized below:

Metric	**Class 1**	**Class 2**	**Class 3**	**Mean/Avg**
Precision	0.40	0.33	0.27	0.34
Recall	0.24	0.02	0.64	0.30
F1-score	0.30	0.04	0.38	0.24
Accuracy	0.30			

Table 3.3: GMM Classification Report for PCA with 1 Component (2 Mixtures)

The GMM classifier with 2 mixtures achieved an overall accuracy of 0.30, with Class 3 performing relatively better, but precision and recall for Class 2 were poor.

3.2.1.4 Confusion Matrix for GMM Classifier with 2 Mixtures (PCA with 1 Component)

The confusion matrix for the GMM classifier with 2 mixtures on the PCA-reduced dataset with 1 component is as follows:

	Class 1	Class 2	Class 3
Class 1	12	0	38
Class 2	2	1	47
Class 3	16	2	32

Table 3.4: Confusion Matrix for GMM Classifier with 2 Mixtures (PCA with 1 Component)

The confusion matrix shows that Class 1 is heavily misclassified as Class 3, and Class 2 is poorly classified.

3.2.1.5 Classification Report for GMM Classifier with 4 Mixtures (PCA with 1 Component)

The classification report for the GMM classifier with 4 mixtures on the PCA-reduced dataset with 1 component is summarized below:

Metric	Class 1	Class 2	Class 3	Mean/Avg
Precision	0.24	0.17	0.27	0.23
Recall	0.30	0.02	0.44	0.25
F1-score	0.27	0.04	0.33	0.21
Accuracy	0.25			

Table 3.5: GMM Classification Report for PCA with 1 Component (4 Mixtures)

The GMM classifier with 4 mixtures has poor performance, with an accuracy of 0.25. Class 3 performs slightly better, but overall performance is weak.

3.2.1.6 Confusion Matrix for GMM Classifier with 4 Mixtures (PCA with 1 Component)

The confusion matrix for the GMM classifier with 4 mixtures on the PCA-reduced dataset with 1 component is as follows:

	Class 1	Class 2	Class 3
Class 1	15	3	32
Class 2	21	1	28
Class 3	26	2	22

Table 3.6: Confusion Matrix for GMM Classifier with 4 Mixtures (PCA with 1 Component)

The confusion matrix highlights that Class 1 is misclassified mostly as Class 3, and Class 2 is misclassified heavily.

3.2.1.7 Classification Report for GMM Classifier with 8 Mixtures (PCA with 1 Component)

The classification report for the GMM classifier with 8 mixtures on the PCA-reduced dataset with 1 component is summarized below:

Metric	**Class 1**	**Class 2**	**Class 3**	**Mean/Avg**
Precision	0.29	0.14	0.30	0.24
Recall	0.38	0.02	0.46	0.29
F1-score	0.33	0.04	0.36	0.24
Accuracy	0.29			

Table 3.7: GMM Classification Report for PCA with 1 Component (8 Mixtures)

The GMM classifier with 8 mixtures shows slightly better results than with fewer mixtures, but still struggles with precision and recall, especially for Class 2.

3.2.1.8 Confusion Matrix for GMM Classifier with 8 Mixtures (PCA with 1 Component)

The confusion matrix for the GMM classifier with 8 mixtures on the PCA-reduced dataset with 1 component is as follows:

	Class 1	**Class 2**	**Class 3**
Class 1	19	3	28
Class 2	23	1	26
Class 3	24	3	23

Table 3.8: Confusion Matrix for GMM Classifier with 8 Mixtures (PCA with 1 Component)

The confusion matrix shows that Class 3 was better classified compared to Class 1 and Class 2.

3.2.1.9 Classification Report for Unimodal Gaussian Classifier (PCA with 2 Components)

The classification report for the Unimodal Gaussian Classifier on the PCA-reduced dataset with 2 components is summarized below:

Metric	Class 1	Class 2	Class 3	Mean/Avg
Precision	0.00	0.33	0.00	0.11
Recall	0.00	1.00	0.00	0.33
F1-score	0.00	0.50	0.00	0.17
Accuracy	0.33			

Table 3.9: Unimodal Gaussian Classification Report for PCA with 2 Components

The Unimodal Gaussian Classifier achieved an overall accuracy of 0.33, with Class 2 showing perfect recall, but precision and F1-scores were low across all classes.

3.2.1.10 Confusion Matrix for Unimodal Gaussian Classifier (PCA with 2 Components)

The confusion matrix for the Unimodal Gaussian Classifier on the PCA-reduced dataset with 2 components is as follows:

	Class 1	Class 2	Class 3
Class 1	0	50	0
Class 2	0	50	0
Class 3	0	50	0

Table 3.10: Confusion Matrix for Unimodal Gaussian Classifier (PCA with 2 Components)

The confusion matrix shows that all instances of Classes 1, 2, and 3 are classified into Class 2.

3.2.1.11 Classification Report for GMM Classifier with 2 Mixtures (PCA with 2 Components)

The classification report for the GMM classifier with 2 mixtures on the PCA-reduced dataset with 2 components is summarized below:

Metric	Class 1	Class 2	Class 3	Mean/Avg
Precision	0.48	0.25	0.34	0.35
Recall	0.40	0.02	0.70	0.37
F1-score	0.43	0.04	0.45	0.31
Accuracy	0.37			

Table 3.11: GMM Classification Report for PCA with 2 Components (2 Mixtures)

The GMM classifier with 2 mixtures achieved an overall accuracy of 0.37, with Class 3 performing the best in terms of recall.

3.2.1.12 Confusion Matrix for GMM Classifier with 2 Mixtures (PCA with 2 Components)

The confusion matrix for the GMM classifier with 2 mixtures on the PCA-reduced dataset with 2 components is as follows:

	Class 1	**Class 2**	**Class 3**
Class 1	20	1	29
Class 2	9	1	40
Class 3	13	2	35

Table 3.12: Confusion Matrix for GMM Classifier with 2 Mixtures (PCA with 2 Components)

The confusion matrix highlights that Class 1 is misclassified heavily as Class 3, and Class 2 instances are also misclassified as Class 3.

3.2.1.13 Classification Report for GMM Classifier with 4 Mixtures (PCA with 2 Components)

The classification report for the GMM classifier with 4 mixtures on the PCA-reduced dataset with 2 components is summarized below:

Metric	**Class 1**	**Class 2**	**Class 3**	**Mean/Avg**
Precision	0.44	0.11	0.35	0.30
Recall	0.28	0.02	0.76	0.35
F1-score	0.34	0.03	0.48	0.28
Accuracy	0.35			

Table 3.13: GMM Classification Report for PCA with 2 Components (4 Mixtures)

The GMM classifier with 4 mixtures performed similarly to the 2-mixture model, with Class 3 having the best performance in terms of recall.

3.2.1.14 Confusion Matrix for GMM Classifier with 4 Mixtures (PCA with 2 Components)

The confusion matrix for the GMM classifier with 4 mixtures on the PCA-reduced dataset with 2 components is as follows:

	Class 1	Class 2	Class 3
Class 1	14	5	31
Class 2	9	1	40
Class 3	9	3	38

Table 3.14: Confusion Matrix for GMM Classifier with 4 Mixtures (PCA with 2 Components)

The confusion matrix reveals that Class 1 and Class 3 are misclassified, with Class 1 being mostly classified as Class 3.

3.2.1.15 Classification Report for GMM Classifier with 8 Mixtures (PCA with 2 Components)

The classification report for the GMM classifier with 8 mixtures on the PCA-reduced dataset with 2 components is summarized below:

Metric	Class 1	Class 2	Class 3	Mean/Avg
Precision	0.39	0.12	0.31	0.28
Recall	0.26	0.04	0.62	0.31
F1-score	0.31	0.06	0.41	0.26
Accuracy	0.31			

Table 3.15: GMM Classification Report for PCA with 2 Components (8 Mixtures)

The GMM classifier with 8 mixtures shows a drop in performance, with overall low precision and recall for Class 2.

3.2.1.16 Confusion Matrix for GMM Classifier with 8 Mixtures (PCA with 2 Components)

The confusion matrix for the GMM classifier with 8 mixtures on the PCA-reduced dataset with 2 components is as follows:

	Class 1	Class 2	Class 3
Class 1	13	7	30
Class 2	8	2	40
Class 3	12	7	31

Table 3.16: Confusion Matrix for GMM Classifier with 8 Mixtures (PCA with 2 Components)

The confusion matrix shows a similar trend to the 4-mixture model, with Class 3 being better identified than Class 1 and Class 2.

3.2.1.17 Classification Report for Unimodal Gaussian Classifier (PCA with 2 Components)

The classification report for the Unimodal Gaussian Classifier on the PCA-reduced dataset with 2 components is summarized below:

Metric	**Class 1**	**Class 2**	**Class 3**	**Mean/Avg**
Precision	0.00	0.33	0.00	0.11
Recall	0.00	1.00	0.00	0.33
F1-score	0.00	0.50	0.00	0.17
Accuracy	0.33			

Table 3.17: Unimodal Gaussian Classification Report for PCA with 2 Components

The Unimodal Gaussian Classifier achieved an overall accuracy of 0.33, with Class 2 showing perfect recall, but precision and F1-scores were low across all classes.

3.2.1.18 Confusion Matrix for Unimodal Gaussian Classifier (PCA with 2 Components)

The confusion matrix for the Unimodal Gaussian Classifier on the PCA-reduced dataset with 2 components is as follows:

	Class 1	**Class 2**	**Class 3**
Class 1	0	50	0
Class 2	0	50	0
Class 3	0	50	0

Table 3.18: Confusion Matrix for Unimodal Gaussian Classifier (PCA with 2 Components)

The confusion matrix shows that all instances of Classes 1, 2, and 3 are classified into Class 2.

3.2.1.19 Classification Report for GMM Classifier with 2 Mixtures (PCA with 2 Components)

The classification report for the GMM classifier with 2 mixtures on the PCA-reduced dataset with 2 components is summarized below:

Metric	Class 1	Class 2	Class 3	Mean/Avg
Precision	0.48	0.25	0.34	0.35
Recall	0.40	0.02	0.70	0.37
F1-score	0.43	0.04	0.45	0.31
Accuracy	0.37			

Table 3.19: GMM Classification Report for PCA with 2 Components (2 Mixtures)

The GMM classifier with 2 mixtures achieved an overall accuracy of 0.37, with Class 3 performing the best in terms of recall.

3.2.1.20 Confusion Matrix for GMM Classifier with 2 Mixtures (PCA with 2 Components)

The confusion matrix for the GMM classifier with 2 mixtures on the PCA-reduced dataset with 2 components is as follows:

	Class 1	Class 2	Class 3
Class 1	20	1	29
Class 2	9	1	40
Class 3	13	2	35

Table 3.20: Confusion Matrix for GMM Classifier with 2 Mixtures (PCA with 2 Components)

The confusion matrix highlights that Class 1 is misclassified heavily as Class 3, and Class 2 instances are also misclassified as Class 3.

3.2.1.21 Classification Report for GMM Classifier with 4 Mixtures (PCA with 2 Components)

The classification report for the GMM classifier with 4 mixtures on the PCA-reduced dataset with 2 components is summarized below:

Metric	Class 1	Class 2	Class 3	Mean/Avg
Precision	0.44	0.11	0.35	0.30
Recall	0.28	0.02	0.76	0.35
F1-score	0.34	0.03	0.48	0.28
Accuracy	0.35			

Table 3.21: GMM Classification Report for PCA with 2 Components (4 Mixtures)

The GMM classifier with 4 mixtures performed similarly to the 2-mixture model, with Class 3 having the best performance in terms of recall.

3.2.1.22 Confusion Matrix for GMM Classifier with 4 Mixtures (PCA with 2 Components)

The confusion matrix for the GMM classifier with 4 mixtures on the PCA-reduced dataset with 2 components is as follows:

	Class 1	**Class 2**	**Class 3**
Class 1	14	5	31
Class 2	9	1	40
Class 3	9	3	38

Table 3.22: Confusion Matrix for GMM Classifier with 4 Mixtures (PCA with 2 Components)

The confusion matrix reveals that Class 1 and Class 3 are misclassified, with Class 1 being mostly classified as Class 3.

3.2.1.23 Classification Report for GMM Classifier with 8 Mixtures (PCA with 2 Components)

The classification report for the GMM classifier with 8 mixtures on the PCA-reduced dataset with 2 components is summarized below:

Metric	**Class 1**	**Class 2**	**Class 3**	**Mean/Avg**
Precision	0.39	0.12	0.31	0.28
Recall	0.26	0.04	0.62	0.31
F1-score	0.31	0.06	0.41	0.26
Accuracy	0.31			

Table 3.23: GMM Classification Report for PCA with 2 Components (8 Mixtures)

The GMM classifier with 8 mixtures shows a drop in performance, with overall low precision and recall for Class 2.

3.2.1.24 Confusion Matrix for GMM Classifier with 8 Mixtures (PCA with 2 Components)

The confusion matrix for the GMM classifier with 8 mixtures on the PCA-reduced dataset with 2 components is as follows:

	Class 1	Class 2	Class 3
Class 1	13	7	30
Class 2	8	2	40
Class 3	12	7	31

Table 3.24: Confusion Matrix for GMM Classifier with 8 Mixtures (PCA with 2 Components)

The confusion matrix shows a similar trend to the 4-mixture model, with Class 3 being better identified than Class 1 and Class 2.

3.2.1.25 Classification Report for Unimodal Gaussian Classifier (PCA with 8 Components)

The classification report for the Unimodal Gaussian Classifier on the PCA-reduced dataset with 8 components is summarized below:

Metric	Class 1	Class 2	Class 3	Mean/Avg
Precision	0.00	0.00	0.33	0.11
Recall	0.00	0.00	1.00	0.33
F1-score	0.00	0.00	0.50	0.17
Accuracy	0.33			

Table 3.25: Unimodal Gaussian Classification Report for PCA with 8 Components

The Unimodal Gaussian Classifier achieved an overall accuracy of 0.33, with Class 3 being identified correctly but at the expense of very poor performance for Classes 1 and 2.

3.2.1.26 Confusion Matrix for Unimodal Gaussian Classifier (PCA with 8 Components)

The confusion matrix for the Unimodal Gaussian Classifier on the PCA-reduced dataset with 8 components is as follows:

	Class 1	Class 2	Class 3
Class 1	0	0	50
Class 2	0	0	50
Class 3	0	0	50

Table 3.26: Confusion Matrix for Unimodal Gaussian Classifier (PCA with 8 Components)

The confusion matrix shows that all instances of Classes 1 and 2 are misclassified as Class 3, with perfect classification for Class 3.

3.2.1.27 Classification Report for GMM Classifier with 2 Mixtures (PCA with 8 Components)

The classification report for the GMM classifier with 2 mixtures on the PCA-reduced dataset with 8 components is summarized below:

Metric	**Class 1**	**Class 2**	**Class 3**	**Mean/Avg**
Precision	0.33	0.31	0.42	0.35
Recall	0.16	0.38	0.54	0.36
F1-score	0.22	0.34	0.47	0.34
Accuracy	0.36			

Table 3.27: GMM Classification Report for PCA with 8 Components (2 Mixtures)

The GMM classifier with 2 mixtures achieved an accuracy of 0.36, with Class 3 performing better in recall and F1-score.

3.2.1.28 Confusion Matrix for GMM Classifier with 2 Mixtures (PCA with 8 Components)

The confusion matrix for the GMM classifier with 2 mixtures on the PCA-reduced dataset with 8 components is as follows:

	Class 1	**Class 2**	**Class 3**
Class 1	8	25	17
Class 2	10	19	21
Class 3	6	17	27

Table 3.28: Confusion Matrix for GMM Classifier with 2 Mixtures (PCA with 8 Components)

The confusion matrix shows that the GMM classifier with 2 mixtures struggles with accurate classification for Class 1 and Class 2 but performs better for Class 3.

3.2.1.29 Classification Report for GMM Classifier with 4 Mixtures (PCA with 8 Components)

The classification report for the GMM classifier with 4 mixtures on the PCA-reduced dataset with 8 components is summarized below:

Metric	Class 1	Class 2	Class 3	Mean/Avg
Precision	0.34	0.00	0.34	0.23
Recall	0.44	0.00	0.54	0.33
F1-score	0.38	0.00	0.42	0.27
Accuracy	0.33			

Table 3.29: GMM Classification Report for PCA with 8 Components (4 Mixtures)

The GMM classifier with 4 mixtures performed poorly overall, achieving an accuracy of 0.33 with Class 2 being the least successful.

3.2.1.30 Confusion Matrix for GMM Classifier with 4 Mixtures (PCA with 8 Components)

The confusion matrix for the GMM classifier with 4 mixtures on the PCA-reduced dataset with 8 components is as follows:

	Class 1	Class 2	Class 3
Class 1	22	4	24
Class 2	22	0	28
Class 3	21	2	27

Table 3.30: Confusion Matrix for GMM Classifier with 4 Mixtures (PCA with 8 Components)

The confusion matrix reveals that Classes 1 and 2 are often misclassified as Class 3, with limited success for all classes.

3.2.1.31 Classification Report for GMM Classifier with 8 Mixtures (PCA with 8 Components)

The classification report for the GMM classifier with 8 mixtures on the PCA-reduced dataset with 8 components is summarized below:

Metric	Class 1	Class 2	Class 3	Mean/Avg
Precision	0.36	0.67	0.40	0.48
Recall	0.18	0.24	0.86	0.43
F1-score	0.24	0.35	0.55	0.38
Accuracy	0.43			

Table 3.31: GMM Classification Report for PCA with 8 Components (8 Mixtures)

The GMM classifier with 8 mixtures performed better than the 4-mixture model, achieving an accuracy of 0.43, with Class 3 being highly successful in terms of recall.

3.2.1.32 Confusion Matrix for GMM Classifier with 8 Mixtures (PCA with 8 Components)

The confusion matrix for the GMM classifier with 8 mixtures on the PCA-reduced dataset with 8 components is as follows:

	Class 1	**Class 2**	**Class 3**
Class 1	9	5	36
Class 2	10	12	28
Class 3	6	1	43

Table 3.32: Confusion Matrix for GMM Classifier with 8 Mixtures (PCA with 8 Components)

The confusion matrix shows better performance for Class 3 in the GMM classifier with 8 mixtures, with improved classification compared to the other classes.

3.2.1.33 Classification Report for Unimodal Gaussian Classifier (PCA with 16 Components)

The classification report for the Unimodal Gaussian Classifier on the PCA-reduced dataset with 16 components is summarized below:

Metric	**Class 1**	**Class 2**	**Class 3**	**Mean/Avg**
Precision	0.29	0.00	0.32	0.20
Recall	0.18	0.00	0.76	0.31
F1-score	0.22	0.00	0.45	0.22
Accuracy	0.31			

Table 3.33: Unimodal Gaussian Classification Report for PCA with 16 Components

The Unimodal Gaussian Classifier achieved an overall accuracy of 0.31, with Class 3 being identified most accurately, while Classes 1 and 2 performed poorly.

3.2.1.34 Confusion Matrix for Unimodal Gaussian Classifier (PCA with 16 Components)

The confusion matrix for the Unimodal Gaussian Classifier on the PCA-reduced dataset with 16 components is as follows:

	Class 1	Class 2	Class 3
Class 1	9	0	41
Class 2	10	0	40
Class 3	12	0	38

Table 3.34: Confusion Matrix for Unimodal Gaussian Classifier (PCA with 16 Components)

The confusion matrix shows that Classes 1 and 2 are often misclassified as Class 3, with perfect classification for Class 3.

3.2.1.35 Classification Report for GMM Classifier with 2 Mixtures (PCA with 16 Components)

The classification report for the GMM classifier with 2 mixtures on the PCA-reduced dataset with 16 components is summarized below:

Metric	Class 1	Class 2	Class 3	Mean/Avg
Precision	0.35	0.36	0.51	0.41
Recall	0.46	0.08	0.76	0.43
F1-score	0.40	0.13	0.61	0.38
Accuracy	0.43			

Table 3.35: GMM Classification Report for PCA with 16 Components (2 Mixtures)

The GMM classifier with 2 mixtures achieved an accuracy of 0.43, with Class 3 performing best.

3.2.1.36 Confusion Matrix for GMM Classifier with 2 Mixtures (PCA with 16 Components)

The confusion matrix for the GMM classifier with 2 mixtures on the PCA-reduced dataset with 16 components is as follows:

	Class 1	Class 2	Class 3
Class 1	23	6	21
Class 2	31	4	15
Class 3	11	1	38

Table 3.36: Confusion Matrix for GMM Classifier with 2 Mixtures (PCA with 16 Components)

The confusion matrix shows that the GMM classifier with 2 mixtures performs better for Class 3, but struggles with Class 2.

3.2.1.37 Classification Report for GMM Classifier with 4 Mixtures (PCA with 16 Components)

The classification report for the GMM classifier with 4 mixtures on the PCA-reduced dataset with 16 components is summarized below:

Metric	**Class 1**	**Class 2**	**Class 3**	**Mean/Avg**
Precision	0.33	0.38	0.20	0.30
Recall	0.58	0.06	0.22	0.29
F1-score	0.42	0.10	0.21	0.25
Accuracy	0.29			

Table 3.37: GMM Classification Report for PCA with 16 Components (4 Mixtures)

The GMM classifier with 4 mixtures performed poorly overall, achieving an accuracy of 0.29, with particularly low performance for Class 2.

3.2.1.38 Confusion Matrix for GMM Classifier with 4 Mixtures (PCA with 16 Components)

The confusion matrix for the GMM classifier with 4 mixtures on the PCA-reduced dataset with 16 components is as follows:

	Class 1	**Class 2**	**Class 3**
Class 1	29	5	16
Class 2	20	3	27
Class 3	39	0	11

Table 3.38: Confusion Matrix for GMM Classifier with 4 Mixtures (PCA with 16 Components)

The confusion matrix reveals that the classifier misclassifies a significant number of instances from Class 1 as Class 3 and struggles with Class 2.

3.2.1.39 Classification Report for GMM Classifier with 8 Mixtures (PCA with 16 Components)

The classification report for the GMM classifier with 8 mixtures on the PCA-reduced dataset with 16 components is summarized below:

Metric	Class 1	Class 2	Class 3	Mean/Avg
Precision	0.33	0.00	0.00	0.11
Recall	1.00	0.00	0.00	0.33
F1-score	0.50	0.00	0.00	0.17
Accuracy	0.33			

Table 3.39: GMM Classification Report for PCA with 16 Components (8 Mixtures)

The GMM classifier with 8 mixtures shows an accuracy of 0.33, with Class 1 being perfectly identified, but Classes 2 and 3 being misclassified.

3.2.1.40 Confusion Matrix for GMM Classifier with 8 Mixtures (PCA with 16 Components)

The confusion matrix for the GMM classifier with 8 mixtures on the PCA-reduced dataset with 16 components is as follows:

	Class 1	Class 2	Class 3
Class 1	50	0	0
Class 2	50	0	0
Class 3	50	0	0

Table 3.40: Confusion Matrix for GMM Classifier with 8 Mixtures (PCA with 16 Components)

The confusion matrix shows that all instances from Classes 1, 2, and 3 are misclassified as Class 1, resulting in an overall poor classification performance for this model.

3.2.1.41 Plots of eigenvalues and 2d reduced dimensional representations

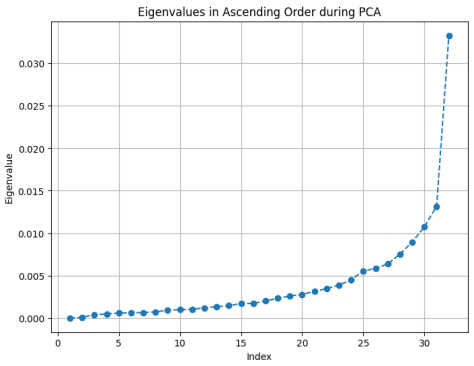

Figure 3.1: Eigenvalues in Ascending Order during PCA

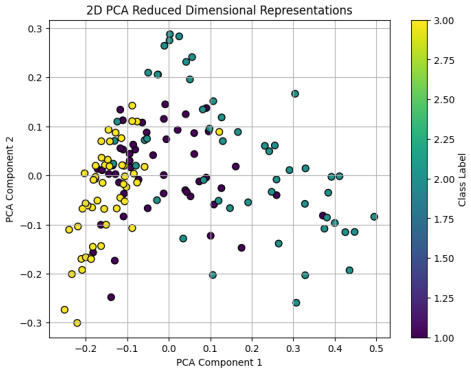

Figure 3.2: 2D PCA Reduced Dimensional Representations

3.2.2 Bayes Classifier using KNN

In this section, we present the results of the Bayes classifier using the K-nearest neighbors (KNN) method for different values of k (1, 3, 5, 7, and 9) on Dataset 2. The classification performance is evaluated based on various metrics such as precision, recall, F1-score, and accuracy.

3.2.2.1 Classification Report

The classification reports for different values of k are summarized below. The metrics include precision, recall, F1-score, and accuracy, which are reported for each class, along with their mean values.

Metric	**Class 1**	**Class 2**	**Class 3**	**Mean/Avg**
Precision (k=1)	0.30	0.33	0.31	0.32
Recall (k=1)	0.54	0.04	0.34	0.31
F1-score (k=1)	0.39	0.07	0.32	0.26
Accuracy (k=1)	0.31			

Table 3.41: KNN Bayes Classifier Report for $k = 1$

Metric	Class 1	Class 2	Class 3	Mean/Avg
Precision (k=3)	0.35	0.88	0.38	0.54
Recall (k=3)	0.66	0.14	0.36	0.39
F1-score (k=3)	0.46	0.24	0.37	0.36
Accuracy (k=3)	0.39			

Table 3.42: KNN Bayes Classifier Report for $k = 3$

Metric	Class 1	Class 2	Class 3	Mean/Avg
Precision (k=5)	0.34	0.75	0.36	0.48
Recall (k=5)	0.68	0.12	0.30	0.37
F1-score (k=5)	0.45	0.21	0.33	0.33
Accuracy (k=5)	0.37			

Table 3.43: KNN Bayes Classifier Report for $k = 5$

Metric	Class 1	Class 2	Class 3	Mean/Avg
Precision (k=7)	0.34	0.86	0.34	0.51
Recall (k=7)	0.74	0.12	0.24	0.37
F1-score (k=7)	0.47	0.21	0.28	0.32
Accuracy (k=7)	0.37			

Table 3.44: KNN Bayes Classifier Report for $k = 7$

3.2.3 Fisher Linear Discriminant Analysis

In this section, we present the results of Fisher Linear Discriminant Analysis (FDA) applied to Dataset 2. We perform FDA with both a unimodal Gaussian classifier and a Gaussian Mixture Model (GMM) with different numbers of components (2 and 4). The classification results for each pair of classes are as follows:

3.2.3.1 FDA + Unimodal Gaussian Classifier

The classification results for the One-vs-One strategy using FDA with a unimodal Gaussian classifier are shown below:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.33	0.20	0.37	0.30
Recall	0.44	0.02	0.58	0.35
F1-score	0.38	0.04	0.45	0.29
Accuracy	0.35			

Table 3.45: One-vs-One FDA + Unimodal Gaussian Classifier Report

3.2.3.2 FDA + GMM (2 components)

For the One-vs-One strategy using FDA with a Gaussian Mixture Model (GMM) with 2 components, the classification results are as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.32	0.25	0.39	0.32
Recall	0.44	0.02	0.60	0.35
F1-score	0.37	0.04	0.47	0.29
Accuracy	0.35			

Table 3.46: FDA + GMM (2 components) Classifier Report

3.2.3.3 FDA + GMM (4 components)

For the One-vs-One strategy using FDA with a Gaussian Mixture Model (GMM) with 4 components, the classification results are as follows:

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.35	0.38	0.43	0.38
Recall	0.52	0.06	0.58	0.39
F1-score	0.42	0.10	0.49	0.34
Accuracy	0.39			

Table 3.47: FDA + GMM (4 components) Classifier Report

3.2.4 Perceptron Based Classifier

In this section, we present the results for the Perceptron-based classifier on Dataset 2. The classifier was trained using a maximum of 2000 iterations. The performance is evaluated in terms of precision, recall, F1-score, accuracy, and the number of iterations until convergence. We also provide the decision boundary plot for the Perceptron classifier.

3.2.4.1 Classification Report

The classification report for the Perceptron classifier with a maximum of 2000 iterations is summarized in the table below. The metrics include precision, recall, F1-score, and accuracy, reported for each class, along with their mean values.

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.30	0.17	0.35	0.27
Recall	0.34	0.02	0.62	0.33
F1-score	0.32	0.04	0.45	0.27
Accuracy	0.33			

Table 3.48: Perceptron Classification Report for max_iter = 2000

The Perceptron classifier achieved an overall accuracy of 0.33 on the test data. The precision, recall, and F1-scores for Class 1 were very low, indicating difficulty in correctly classifying this class. However, Class 2 exhibited better performance with a recall of 0.62 and an F1-score of 0.45. The classifier struggled with Class 0, showing moderate performance with a recall of 0.34 and precision of 0.30.

3.2.4.2 Number of Iterations until Convergence

The Perceptron classifier achieved convergence in **10 iterations**. The training and test accuracies were as follows:

- **Training Accuracy**: 0.8667 - **Test Accuracy**: 0.3267

These results suggest that the Perceptron classifier struggled with this dataset, achieving only modest performance. The low precision and recall values, especially for Class 1, indicate significant room for improvement in classification performance.

3.2.5 Logistic Regression Classifier

In this section, we present the results for the Logistic Regression classifier on Dataset 2. The classifier achieved perfect classification performance across all metrics. The following subsections include the classification report, confusion matrix, and the decision boundary plot.

3.2.5.1 Classification Report

The classification report for the Logistic Regression classifier is summarized below. The classifier showed poor performance, with low precision and recall for Classes 0 and 1, while Class 2 demonstrated a better performance.

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.32	0.04	0.53	0.32
Recall	0.48	0.02	0.75	0.35
F1-score	0.38	0.04	0.62	0.30
Accuracy	0.35			

Table 3.49: Logistic Regression Classification Report

The Logistic Regression classifier achieved an overall accuracy of 0.35 on the test data. The precision, recall, and F1-scores for Class 0 were moderate, while for Class 1, they were very low. Class 2 exhibited a much better performance, with a recall of 0.75 and an F1-score of 0.62, suggesting that the classifier performed better when distinguishing Class 2 from the others.

3.2.5.2 Confusion Matrix

The confusion matrix for the Logistic Regression classifier on the test data is as follows:

	Class 0	Class 1	Class 2
Class 0	24	2	24
Class 1	24	1	25
Class 2	21	1	28

Table 3.50: Confusion Matrix for Logistic Regression Classifier

The confusion matrix reveals that the classifier struggled with correctly classifying Classes 0 and 1. Both classes were often misclassified as Class 2, as indicated by the high values in the Class 2 column for both Class 0 and Class 1. For Class 2, the classifier was able to correctly classify most instances (28 out of 50), with some misclassification into Classes 0 and 1.

3.2.5.3 Observations

The Logistic Regression classifier shows modest overall accuracy but faced significant challenges in distinguishing Classes 0 and 1. Most of the misclassified instances were shifted to Class 2, which suggests that the model may benefit from further tuning, including the exploration of different features or the use of more advanced classification techniques.

3.2.6 SVM Based Classifier

In this section, we evaluate the performance of the Support Vector Machine (SVM) classifier on Dataset 2.

3.2.6.1 Tuning Linear Kernel SVM

The classification report for the Linear Kernel SVM is summarized below. The model achieved a moderate performance, with precision and recall values of 0.366 and 0.387, respectively. The classifier struggled with the classification of Classes 0 and 1.

Metric	**Class 0**	**Class 1**	**Class 2**	**Mean/Avg**
Precision	0.38	0.04	0.53	0.37
Recall	0.44	0.02	0.75	0.39
F1-score	0.32	0.02	0.62	0.31
Accuracy	0.39			

Table 3.51: Linear Kernel SVM Classification Report

The Linear Kernel SVM achieved an accuracy of 0.387 on the test data. The classifier performed best for Class 2, with a recall of 0.75 and an F1-score of 0.62, but struggled with Classes 0 and 1, especially with a recall of only 0.02 for Class 1.

3.2.6.2 Confusion Matrix for Linear Kernel SVM

The confusion matrix for the Linear Kernel SVM on the test data is as follows:

	Class 0	**Class 1**	**Class 2**
Class 0	22	1	27
Class 1	27	1	22
Class 2	14	1	35

Table 3.52: Confusion Matrix for Linear Kernel SVM

The confusion matrix shows that the Linear Kernel SVM struggled with misclassifying Class 0 as Class 2 and vice versa, with several instances of misclassification from Class 1 to Class 2 as well.

3.2.6.3 Tuning Polynomial Kernel SVM

The classification report for the Polynomial Kernel SVM is summarized below. This model exhibited better performance compared to the Linear Kernel SVM, with an accuracy of 0.447 and a balanced F1-score for all classes.

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.43	0.18	0.49	0.43
Recall	0.70	0.12	0.52	0.45
F1-score	0.53	0.06	0.62	0.41
Accuracy	0.45			

Table 3.53: Polynomial Kernel SVM Classification Report

The Polynomial Kernel SVM achieved an accuracy of 0.447. Class 0 was well-classified with a precision of 0.43 and recall of 0.70, while Class 1 showed weaker performance. Class 2 had a precision of 0.49 and recall of 0.52, showing moderate success in distinguishing it from the other classes.

3.2.6.4 Confusion Matrix for Polynomial Kernel SVM

The confusion matrix for the Polynomial Kernel SVM on the test data is as follows:

	Class 0	Class 1	Class 2
Class 0	35	6	9
Class 1	32	6	12
Class 2	18	6	26

Table 3.54: Confusion Matrix for Polynomial Kernel SVM

The confusion matrix indicates that Class 0 was relatively well-classified, with fewer misclassifications. Class 2 was also fairly well-identified, although it was sometimes confused with Class 1.

3.2.6.5 Tuning RBF Kernel SVM

The classification report for the RBF Kernel SVM is summarized below. This model achieved an accuracy of 0.440, with strong precision for Class 0 and a moderate recall for Class 2.

Metric	Class 0	Class 1	Class 2	Mean/Avg
Precision	0.46	0.05	0.67	0.46
Recall	0.56	0.05	0.80	0.47
F1-score	0.50	0.05	0.73	0.36
Accuracy	0.44			

Table 3.55: RBF Kernel SVM Classification Report

The RBF Kernel SVM achieved an accuracy of 0.440. Class 0 exhibited good precision (0.46) and recall (0.56), while Class 2 showed the best performance with a recall of 0.80 and F1-score of 0.73.

3.2.6.6 Confusion Matrix for RBF Kernel SVM

The confusion matrix for the RBF Kernel SVM on the test data is as follows:

	Class 0	**Class 1**	**Class 2**
Class 0	25	1	24
Class 1	30	1	19
Class 2	10	0	40

Table 3.56: Confusion Matrix for RBF Kernel SVM

The confusion matrix for the RBF Kernel SVM shows that Class 0 was fairly well-classified, while Class 2 had a high number of correct classifications (40). Class 1, however, was still misclassified quite frequently.

3.2.6.7 Observations

The three SVM kernels (Linear, Polynomial, and RBF) showed varied performance:

- **Linear Kernel SVM**: Achieved a modest accuracy of 0.39, but had low precision and recall for Classes 0 and 1. - **Polynomial Kernel SVM**: Outperformed the Linear Kernel with an accuracy of 0.45, providing a more balanced performance across all classes. - **RBF Kernel SVM**: Achieved an accuracy of 0.44, with strong performance for Class 2, but struggled with Class 1.

Each kernel has its strengths and limitations, with the Polynomial Kernel showing the most consistent overall performance.

Chapter 4

Comparison of accuracy with all the classifiers

4.1 Linearly Separable dataset

The following table shows the comparison of accuracy with all the classifiers build so far in all the assignments

Table 4.1: comparison of accuracy with all the classifiers for linearly separable dataset

Assignment	**Classifier**	**Accuracy**
1	Bayes Classifier full and different covariance matrix	1.0
	Bayes Classifier diagonal and different covariance matrix	1.0
	Bayes Classifier full and same covariance matrix	1.0
	Bayes Classifier diagonal and same covariance matrix	1.0
4	Bayes Classifier using KNN density estimation for k=1	1.0
	Bayes Classifier using KNN density estimation for k=3	1.0
	Bayes Classifier using KNN density estimation for k=5	1.0
	Bayes Classifier using KNN density estimation for k=7	1.0
	Bayes Classifier using KNN density estimation for k=9	1.0
	One-vs-One FDA + Unimodal Gaussian Classifier	1.0
	One-vs-One FDA + GMM (2 components) Classifier	1.0
	One-vs-One FDA + GMM (4 components) Classifier	1.0
	Perceptron based classifier	0.99
	Logistic regression classifier	1.0
	SVM classifier using linear kernel (best)	1.0
	SVM classifier using polynomial kernel (best)	1.0
	SVM classifier using RBF kernel (best)	1.0

4.2 Non Linearly Separable dataset

The following table shows the comparison of accuracy with all the classifiers build so far in all the assignments

Table 4.2: comparison of accuracy with all the classifiers for non linearly separable dataset

Assignment	**Classifier**	**Accuracy**
1	Bayes Classifier full and different covariance matrix	0.958
	Bayes Classifier diagonal and different covariance matrix	0.953
	Bayes Classifier full and same covariance matrix	0.233
	Bayes Classifier diagonal and same covariance matrix	0.235
2	GMM with number of mixtures=2	0.99
	GMM with number of mixtures=4,8,16,32	1.0
4	Bayes Classifier using KNN density estimation for k=1	1.0
	Bayes Classifier using KNN density estimation for k=3	1.0
	Bayes Classifier using KNN density estimation for k=5	1.0
	Bayes Classifier using KNN density estimation for k=7	1.0
	Bayes Classifier using KNN density estimation for k=9	1.0
	One-vs-One FDA + Unimodal Gaussian Classifier	0.76
	One-vs-One FDA + GMM (2 components) Classifier	0.77
	One-vs-One FDA + GMM (4 components) Classifier	0.79
	Perceptron based classifier	0.34
	Logistic regression classifier	0.37
	SVM classifier using linear kernel (best)	0.5
	SVM classifier using polynomial kernel (best)	1.0
	SVM classifier using RBF kernel (best)	1.0

4.3 Scene Image Dataset dataset

The following table shows the comparison of accuracy with all the classifiers build so far in all the assignments

Table 4.3: comparison of accuracy with all the classifiers for non linearly separable dataset

Assignment	**Classifier**	**Accuracy**
3	GMM with number of mixtures=1	0.2867
	GMM with number of mixtures=2	0.33
	GMM with number of mixtures=4	0.2733
4	PCA with 1 component and bayes classifier with unimodal gaussian (best)	0.34
	PCA with 2 components and bayes classifier with GMM 2 mixtures (best)	0.37
	PCA with 4 components and bayes classifier with GMM 2 mixtures (best)	0.38
	PCA with 8 components and bayes classifier with GMM 8 mixtures (best)	0.43
	Bayes Classifier using KNN density estimation for k=1	1.0
	Bayes Classifier using KNN density estimation for k=3	1.0
	Bayes Classifier using KNN density estimation for k=5	1.0
	Bayes Classifier using KNN density estimation for k=7	1.0
	Bayes Classifier using KNN density estimation for k=9	1.0
	One-vs-One FDA + Unimodal Gaussian Classifier	0.76
	One-vs-One FDA + GMM (2 components) Classifier	0.77
	One-vs-One FDA + GMM (4 components) Classifier	0.79
	Perceptron based classifier	0.34
	Logistic regression classifier	0.37
	SVM classifier using linear kernel (best)	0.5
	SVM classifier using polynomial kernel (best)	1.0
	SVM classifier using RBF kernel (best)	1.0