Faculty of Engineering & Technology

Electrical & Computer Engineering Department

ENCS3340

Artificial Intelligence

Project #2

Comparative Study of Image Classification Using Decision Tree, Naive Bayes, and Feedforward Neural Networks

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1. Introduction

1.1 Project Overview

This project aims to evaluate and compare three widely used machine learning algorithms Naive Bayes, Decision Tree, and Feedforward Neural Networks (MLP) applied to the task of image classification. The dataset used consists of images categorized into three distinct classes: flowers, dogs, and birds. Each model will be trained on this dataset, and their performance will be assessed using key metrics such as accuracy, precision, recall, and F1-score. The project will focus on understanding how each algorithm performs with image data, analyzing their strengths and weaknesses, and determining the most effective approach for classifying images into the given categories.

1.2 Objective

The main goals of this project are as follows:

- To implement and analyze the performance of three distinct machine learning algorithms Naive Bayes, Decision Tree, and Feedforward Neural Networks (MLP) in classifying images into predefined categories.
- To evaluate and compare the models' performance using essential evaluation metrics, including accuracy, precision, recall, and F1-score, to understand their effectiveness.
- To apply dimensionality reduction techniques, such as PCA, to enhance the models' efficiency by reducing the input data's complexity.
- To identify and determine which of the models delivers the best results in terms of classification accuracy and generalization to new, unseen data.

2. Dataset Description

2.1 Dataset Overview

The dataset used in this project consists of images categorized into three distinct classes: flowers, dogs, and birds. Each category contains 1,200 images, providing a balanced and diverse dataset for training and testing the models. The flower category includes images of various species of flowers, the dog category features different breeds of dogs, and the bird category consists of images representing multiple bird species. With 1,200 images per category, the dataset offers a comprehensive set of examples that allow the machine learning models to learn and distinguish the visual features specific to each class. This dataset is essential for evaluating the performance of the models in classifying images across these categories.

2.2 Preprocessing

For the preprocessing of the dataset, all images were resized to a consistent size of 32x32 pixels to standardize the input for the machine learning models. After resizing, each image was flattened into a one-dimensional vector of size 1024, as each 32x32 image has 1024 pixels. This transformation allows the images to be represented as numerical data suitable for machine learning algorithms. Additionally, pixel values were normalized to the range of [0, 1] by dividing by 255.0. This normalization step ensures that the values are within a comparable scale, helping the models to converge more quickly during training and improving overall performance.

2.3 Dimensionality Reduction

To enhance the efficiency of the models and reduce computational complexity, Principal Component Analysis (PCA) was applied to the dataset. PCA was used to transform the high-dimensional image data into a lower-dimensional space while retaining as much of the original variance as possible. In this case, 100 principal components were selected, which preserved 95% of the variance in the dataset. This reduction in the feature set, from 1024 to 100 dimensions, allowed the models to process the data more efficiently, while still capturing the key information necessary for accurate image classification.

3. Models Implemented

3.1 Naive Bayes Classifier

The Naive Bayes classifier is a probabilistic model based on Bayes' Theorem, which calculates the probability of each class given the input features. It assumes that the features (in this case, pixel values of the images) are conditionally independent, which simplifies the computation of class probabilities. The model uses the prior probabilities of each class and the likelihood of each feature given a class to make predictions. For image classification, the Naive Bayes model typically performs well with high-dimensional data like pixel values, as it is computationally efficient and requires less training data compared to other models. However, the independence assumption often limits its ability to capture complex relationships in the data, which can affect its performance on tasks like image classification where feature dependencies are strong.

3.2 Decision Tree Classifier

The Decision Tree classifier builds a tree-like structure where each internal node represents a decision based on a specific feature, and each leaf node represents a class label. The model splits the data based on feature values to create decision rules that help classify new samples. Decision Trees work well with categorical and continuous data and are easily interpretable, as the decisions made by the model can be visualized in the form of a tree. In this project, the Decision Tree classifier was used with a depth of 30 to avoid overfitting while still capturing complex patterns in the data. However, Decision Trees can be prone to overfitting, especially when they are too deep, capturing noise in the data rather than generalizable patterns. They are also sensitive to small variations in the data, which can impact their performance.

3.3 Feedforward Neural Network (MLPClassifier)

The Feedforward Neural Network (MLP) is a type of artificial neural network that consists of multiple layers: an input layer, one or more hidden layers, and an output layer. Each layer is fully connected to the next one, and each connection has a weight that is adjusted during training to minimize the error in the predictions. The MLPClassifier used in this project consists of three hidden layers with 256, 128, and 64 neurons, respectively, and utilizes the ReLU activation function for non-linear transformations. The MLP model is particularly well-suited for complex tasks like image classification, as it can learn intricate patterns in the data through its deep architecture. By training with the Adam optimizer and using early stopping to prevent overfitting, the MLP model can learn more generalizable features, leading to better performance on unseen data. However, training a neural network can be computationally expensive and time-consuming, requiring significant resources and data for optimal performance.

4. Model Evaluation

```
--- Summary Accuracy ---
Naive Bayes: 0.5861
Decision Tree:0.5431
MLP: 0.6028
```

Figure 1: Summary Accuracy.

1) Naive Bayes Classifier

```
=== Naive Bayes Evaluation ===
Accuracy: 0.5861111111111111
Classification Report:
              precision    recall  f1-score   support

        bird       0.54      0.59      0.56       266
         dog       0.56      0.57      0.56       230
      flower       0.70      0.59      0.64       224

    accuracy                           0.59       720
   macro avg       0.60      0.59      0.59       720
weighted avg       0.59      0.59      0.59       720
```

Figure 2: Naive Bayes Evaluation.

```
Confusion Matrix:
 [[158  76  32]
 [ 73 131  26]
 [ 64  27 133]]
```

Figure 3 : Confusion Matrix Interpretation NB.

2) Decision Tree Classifier

Classification Report:

	precision	recall	f1-score	support
bird	0.47	0.45	0.46	266
dog	0.45	0.48	0.46	230
flower	0.57	0.56	0.56	224
accuracy			0.49	720
macro avg	0.50	0.50	0.50	720
weighted avg	0.49	0.49	0.49	720

Figure 4: Decision Tree Evaluation.

```
Confusion Matrix:
 [[120  89  57]
 [ 82 110  38]
 [ 54  45 125]]
```

Figure 5: Confusion Matrix Interpretation DT.

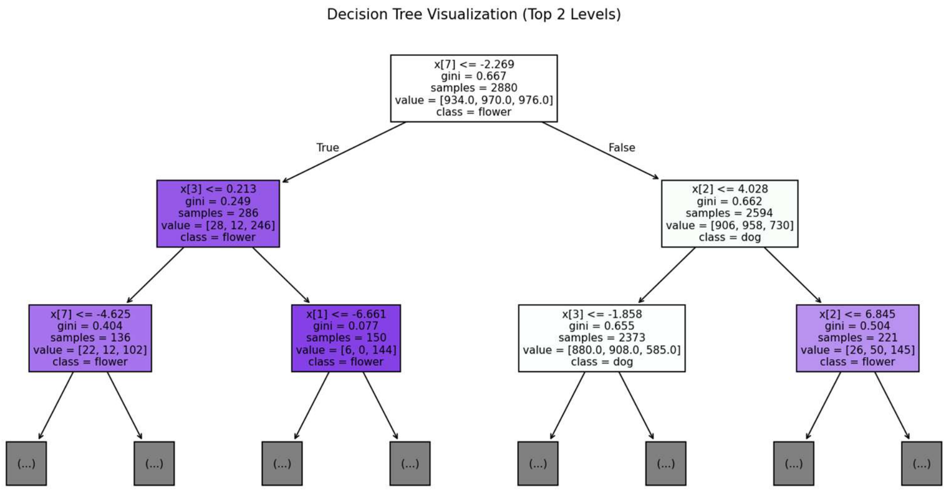

Figure 6: Key Information in the Decision Tree.

3) Feedforward Neural Network

```
=== Feedforward Neural Network (MLP) Evaluation ===
Accuracy: 0.6027777777777777
Classification Report:
              precision    recall  f1-score   support

        bird       0.59      0.53      0.56       266
         dog       0.53      0.60      0.56       230
      flower       0.71      0.69      0.70       224

    accuracy                           0.60       720
   macro avg       0.61      0.61      0.61       720
weighted avg       0.61      0.60      0.60       720
```

Figure 7: Feedforward Neural Network (MLP) Evaluation.

```
Confusion Matrix:
 [[142  92  32]
 [ 61 138  31]
 [ 38  32 154]]
```

Figure 8: Confusion Matrix Interpretation MLP.

5. Discussion

Model	Accuracy	Precision (Macro Avg)	Recall (Macro Avg)	F1-Score (Macro Avg)
Naive Bayes	58.61%	0.60	0.59	0.59
Decision Tree	54.31%	0.50	0.50	0.50
Feedforward Neural Network (MLP)	60.28%	0.61	0.61	0.61

Table 1: Accuracy Comparison Table.

The Feedforward Neural Network (MLP) outperformed both the Naive Bayes and Decision Tree models across all metrics, achieving the highest accuracy of 60.28%. This superior performance can be attributed to the MLP's ability to learn complex, non-linear patterns in the data through its multi-layer architecture. It demonstrated balanced precision, recall, and F1-scores, making it the most suitable model for this image classification task. While the Naive Bayes model showed reasonable performance with an accuracy of 58.61%, particularly for the flower category, it struggled with complex relationships between features due to its assumption of feature independence. This limitation was reflected in its lower F1-scores for the bird and dog categories.

On the other hand, the Decision Tree model performed the worst with an accuracy of 54.31%, showing lower precision and recall across all classes. The Decision Tree's tendency to overfit and its sensitivity to small data variations hindered its ability to generalize effectively to new data. While Decision Trees are interpretable, their performance on high-dimensional image data is limited unless carefully tuned or combined with ensemble methods. Overall, the MLP model is the most effective choice for image classification, but Naive Bayes and Decision Trees may still be useful for simpler tasks or when interpretability is important.

6. Conclusion

In this project, we compared the performance of three machine learning models Naive Bayes, Decision Tree, and Feedforward Neural Network (MLP) on an image classification task involving three categories: flowers, dogs, and birds. After evaluating the models based on accuracy, precision, recall, and F1-score, we found that the MLP model outperformed the others, achieving the highest accuracy of 60.28% and showing balanced performance across all metrics. The MLP's deep architecture allowed it to effectively capture complex patterns in the image data, making it the best choice for this classification task.

While Naive Bayes performed reasonably well with an accuracy of 58.61%, especially for the flower category, its reliance on the assumption of feature independence limited its ability to handle the interdependencies between pixels in image data. Decision Tree, on the other hand, had the lowest accuracy (54.31%) and struggled to generalize, primarily due to overfitting. Although Naive Bayes and Decision Tree models have their advantages, such as simplicity and interpretability, the MLP model emerged as the most robust and effective solution for this image classification problem. Future improvements could involve tuning the Decision Tree model, using ensemble methods, or exploring advanced deep learning models like Convolutional Neural Networks (CNNs) for better performance.