

# solution

November 22, 2024

## 1 Animal Image Classification using PySpark and TensorFlow

This project implements a complete image classification pipeline using PySpark and TensorFlow, processing a large-scale dataset containing 64 different animal classes.

### 1.1 Details

Instituto Tecnológico de Estudios Superiores de Monterrey, campus Querétaro TC3007C.501 - Artificial Intelligence for Data Science

**Task:** Momento de Retroalimentación - Módulo 1 Utilización, procesamiento y visualización de grandes volúmenes de datos

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**Date:** October 29, 2024

```
[1]: import tensorflow as tf
```

```
2024-11-22 19:06:31.305935: I tensorflow/core/util/port.cc:153] oneDNN custom operations are on. You may see slightly different numerical results due to floating-point round-off errors from different computation orders. To turn them off, set the environment variable `TF_ENABLE_ONEDNN_OPTS=0`.
```

```
2024-11-22 19:06:31.315400: E external/local_xla/xla/stream_executor/cuda/cuda_fft.cc:477] Unable to register cuFFT factory: Attempting to register factory for plugin cuFFT when one has already been registered
```

```
WARNING: All log messages before absl::InitializeLog() is called are written to STDERR
```

```
E0000 00:00:1732323991.328346 167592 cuda_dnn.cc:8310] Unable to register cuDNN factory: Attempting to register factory for plugin cuDNN when one has already been registered
```

```
E0000 00:00:1732323991.331624 167592 cuda_blas.cc:1418] Unable to register cuBLAS factory: Attempting to register factory for plugin cuBLAS when one has already been registered
```

```
2024-11-22 19:06:31.343438: I tensorflow/core/platform/cpu_feature_guard.cc:210] This TensorFlow binary is optimized to use available CPU instructions in performance-critical operations.
```

```
To enable the following instructions: AVX2 AVX512F AVX512_VNNI FMA, in other operations, rebuild TensorFlow with the appropriate compiler flags.
```

## 1.2 1. Environment configuration for Big Data Processing

TensorFlow's mixed precision API is used for optimizing GPU performance. Additionally, sufficient memory allocated for image processing and spark configured to handle large data volumes.

### 1.2.1 2.1 Tensorflow

Enables mixed precision training for better performance on GPU

```
[2]: policy = tf.keras.mixed_precision.Policy("mixed_float16")
tf.keras.mixed_precision.set_global_policy(policy)
```

### 1.2.2 2.2 Spark

Initialize Spark with sufficient memory for image processing

```
[3]: from pyspark.sql import SparkSession
```

```
[4]: spark = (
    SparkSession.builder.appName("Image Classification")
    .config("spark.executor.memory", "16g")
    .config("spark.driver.memory", "16g")
    .getOrCreate()
)
```

```
your 131072x1 screen size is bogus. expect trouble
24/11/22 19:06:36 WARN Utils: Your hostname, CARLOSBLADE resolves to a loopback
address: 127.0.1.1; using 10.255.255.254 instead (on interface lo)
24/11/22 19:06:36 WARN Utils: Set SPARK_LOCAL_IP if you need to bind to another
address
Setting default log level to "WARN".
To adjust logging level use sc.setLogLevel(newLevel). For SparkR, use
setLogLevel(newLevel).
24/11/22 19:06:36 WARN NativeCodeLoader: Unable to load native-hadoop library
for your platform... using builtin-java classes where applicable
```

## 1.3 2. Dataset Selection and Analysis

### 1.3.1 2.1 Animal Classification Dataset

This [dataset](#) consists of animal images across 64 different classes, specifically curated for multi-class image classification. Below is a visualization showing one sample image from each class to demonstrate the diversity and characteristics of the dataset.

This project utilizes a large-scale image dataset containing 64 animal classes, specifically chosen for its size and complexity:

- Over 10,000 high-resolution images (512x512 pixels)
- 64 different animal classes
- Balanced distribution of images across classes
- Structured in a hierarchical directory format

- Total size of 6.1 GB

```
[5]: import os
import numpy as np
import matplotlib.pyplot as plt
from PIL import Image
```

```
[6]: def visualize_dataset_samples(data_dir: str, figsize: tuple = (20, 20)) -> None:
    """
    Display sample images from each class in the dataset in a grid layout.

    Args:
        data_dir: str - The directory containing the dataset.
        figsize: tuple - The size of the grid layout.
    """
    class_dirs = sorted(
        [d for d in os.listdir(data_dir) if os.path.isdir(os.path.
        ↪join(data_dir, d))]
    )

    n_classes: int = len(class_dirs)
    grid_size = np.ceil(np.sqrt(n_classes)).astype(int)

    plt.figure(figsize=figsize)
    for idx, class_name in enumerate(class_dirs):
        try:
            class_path = os.path.join(data_dir, class_name)
            image_file = next(
                f for f in os.listdir(class_path) if f.lower().endswith(".png")
            )
            image_path = os.path.join(class_path, image_file)

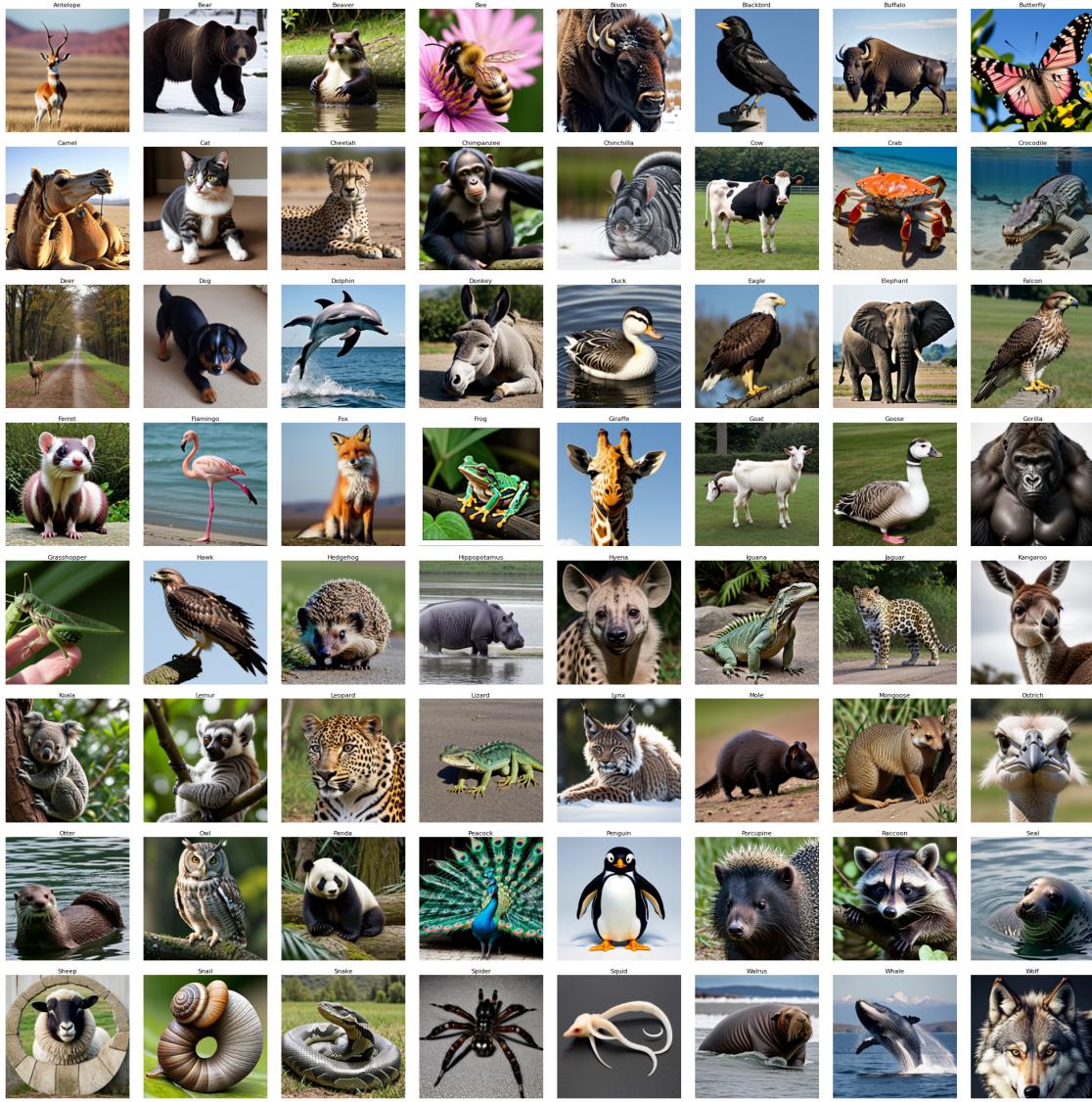
            img = Image.open(image_path)
            img = img.resize((224, 224))

            plt.subplot(grid_size, grid_size, idx + 1)
            plt.imshow(img)
            plt.axis("off")
            plt.title(class_name.capitalize(), fontsize=8, pad=2)

        except Exception as e:
            print(f"Error loading sample from {class_name}: {str(e)}")

    plt.tight_layout()
    plt.show()
```

```
[7]: visualize_dataset_samples("../data/images/")
```



## 1.4 3. Intelligent Model Generation using PySpark and TensorFlow

The following implementation combines PySpark for data handling and Tensorflow for deep learning model training. The pipeline consists of the following steps:

### 1.4.1 3.1 Data Processing Pipeline

- **SparkDataLoader**: handles large-scale image data loading using PySpark.
- **DatasetSplitter**: implements stratified data splitting for balanced training.
- **ImageProcessor**: handles image preprocessing and augmentations.
- **TFDataset**: converts image data into TensorFlow datasets for model training.

**3.1.1 SparkDataLoader Class** The SparkDataLoader class is a utility for loading and processing image datasets using PySpark. It provides methods for reading images from a directory, resizing images, and converting images to NumPy arrays for further processing.

```
[8]: import os
from pathlib import Path
from typing import Dict, Tuple
import pyspark.sql.functions as F
from pyspark.sql import SparkSession, DataFrame

[9]: class SparkDataLoader:
    def __init__(self, spark_session: SparkSession):
        self.spark = spark_session

    def load_from_directory(self, image_dir: str) -> DataFrame:
        """
        Loads the images from the specified directory into a Spark DataFrame.

        Args:
            image_dir: str - The directory containing the images.

        Returns:
            DataFrame - A DataFrame containing the image paths and labels.
        """

        image_dir = os.path.abspath(os.path.expanduser(image_dir))
        base_path = Path(image_dir)

        if not base_path.exists():
            raise ValueError(f"Directory not found: {image_dir}")

        data = []
        for root, _, files in os.walk(base_path):
            for file in files:
                if file.lower().endswith(".png"):
                    full_path = Path(root) / file
                    label = full_path.parent.name

                    data.append({"image_path": str(full_path), "label": label})

        if not data:
            raise ValueError(f"No images found in {image_dir}")

        print(f"Found {len(data)} images in {image_dir}")
        return self.spark.createDataFrame(data)

    def create_label_mappings(
```

```

    self, df: DataFrame
) -> Tuple[Dict[str, int], Dict[int, str]]:
    """
    Creates the label mappings for the dataset.

    Args:
        df: DataFrame - The DataFrame containing the image paths and labels.

    Returns:
        Tuple[Dict[str, int], Dict[int, str]] - A tuple containing the
        ↪label to index and index to label mappings.
    """

    labels = sorted(df.select("label").distinct().toPandas()["label"])
    label_to_index = {name: index for index, name in enumerate(labels)}
    index_to_label = {index: name for name, index in label_to_index.items()}

    return label_to_index, index_to_label

def add_label_indices(
    self, df: DataFrame, label_to_index: Dict[str, int]
) -> DataFrame:
    """
    Creates a new column in the DataFrame containing the label indices.

    Args:
        df: DataFrame - The DataFrame containing the image paths and labels.
        label_to_index: Dict[str, int] - The label to index mapping.

    Returns:
        DataFrame - The DataFrame containing the image paths, labels, and
        ↪label indices.
    """

    mapping_expr = F.create_map([F.lit(x) for x in sum(label_to_index.
    ↪items(), ())])

    return df.withColumn("label_index", mapping_expr[F.col("label")])

```

**3.2 DatasetSplitter Class** The `DatasetSplitter` class implements a stratified data splitting strategy to ensure that each class is represented in both the training and validation sets. This is crucial for training a balanced and robust model.

```
[10]: import pandas as pd
from sklearn.model_selection import train_test_split
```

```
24/11/22 19:06:55 WARN GarbageCollectionMetrics: To enable non-built-in garbage
collector(s) List(G1 Concurrent GC), users should configure it(them) to
spark.eventLog.gcMetrics.youngGenerationGarbageCollectors or
spark.eventLog.gcMetrics.oldGenerationGarbageCollectors
```

```
[11]: class DatasetSplitter:
    @staticmethod
    def split_spark_data(
        df: DataFrame, train_ratio: float = 0.7, val_ratio: float = 0.15
    ) -> Tuple[pd.DataFrame, pd.DataFrame, pd.DataFrame]:
        """
        Split Spark DataFrame into train, validation, and test sets.

        Args:
            df: Input Spark DataFrame
            train_ratio: Proportion of data for training
            val_ratio: Proportion of data for validation

        Returns:
            Tuple of Pandas DataFrames (train, val, test)
        """
        pandas_df = df.toPandas()
        pandas_df["label_index"] = pandas_df["label_index"].astype("int32")

        train_df, temp_df = train_test_split(
            pandas_df,
            train_size=train_ratio,
            random_state=42,
            stratify=pandas_df["label_index"],
        )

        remaining_ratio = val_ratio / (1 - train_ratio)
        val_df, test_df = train_test_split(
            temp_df,
            train_size=remaining_ratio,
            random_state=42,
            stratify=temp_df["label_index"],
        )

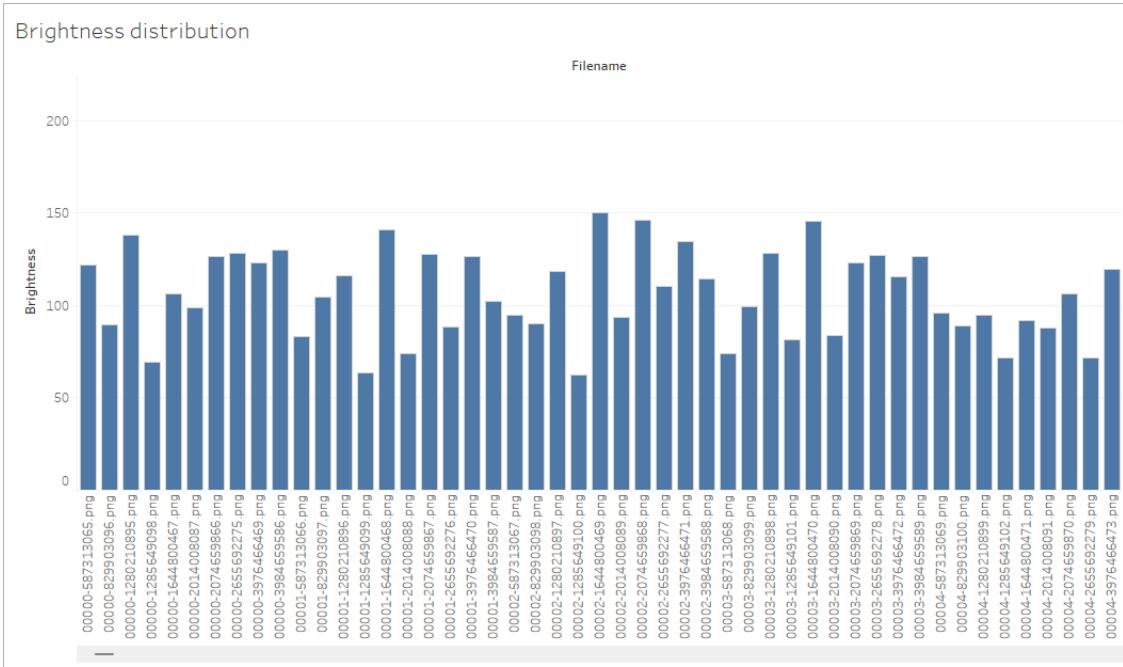
        return train_df, val_df, test_df
```

## 1.5 Data augmentation justifications

Based off the analysis of the metadata from the dataset, the following augmentations were performed to increase the diversity of the training data:

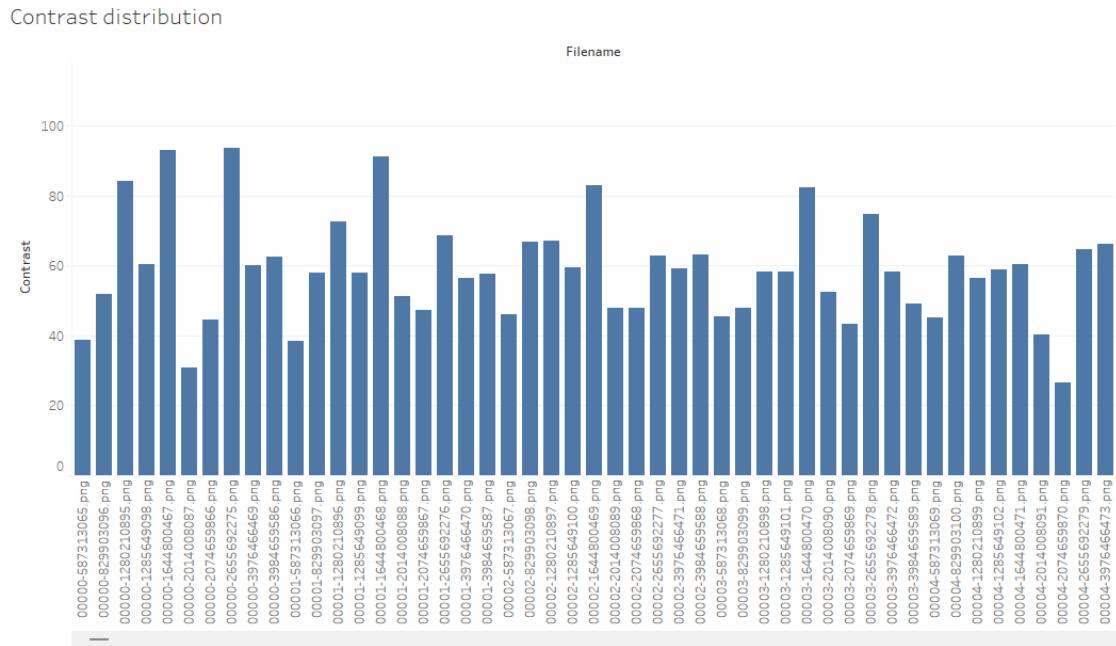
### 1.5.1 Brightness and Contrast Adjustments

Randomly adjust the brightness and contrast of images to simulate different lighting conditions and improve model generalization. The distribution of brightness and contrast levels based off class names is shown below:



The brightness distribution related to each individual file, showing the range of brightness values across the dataset.

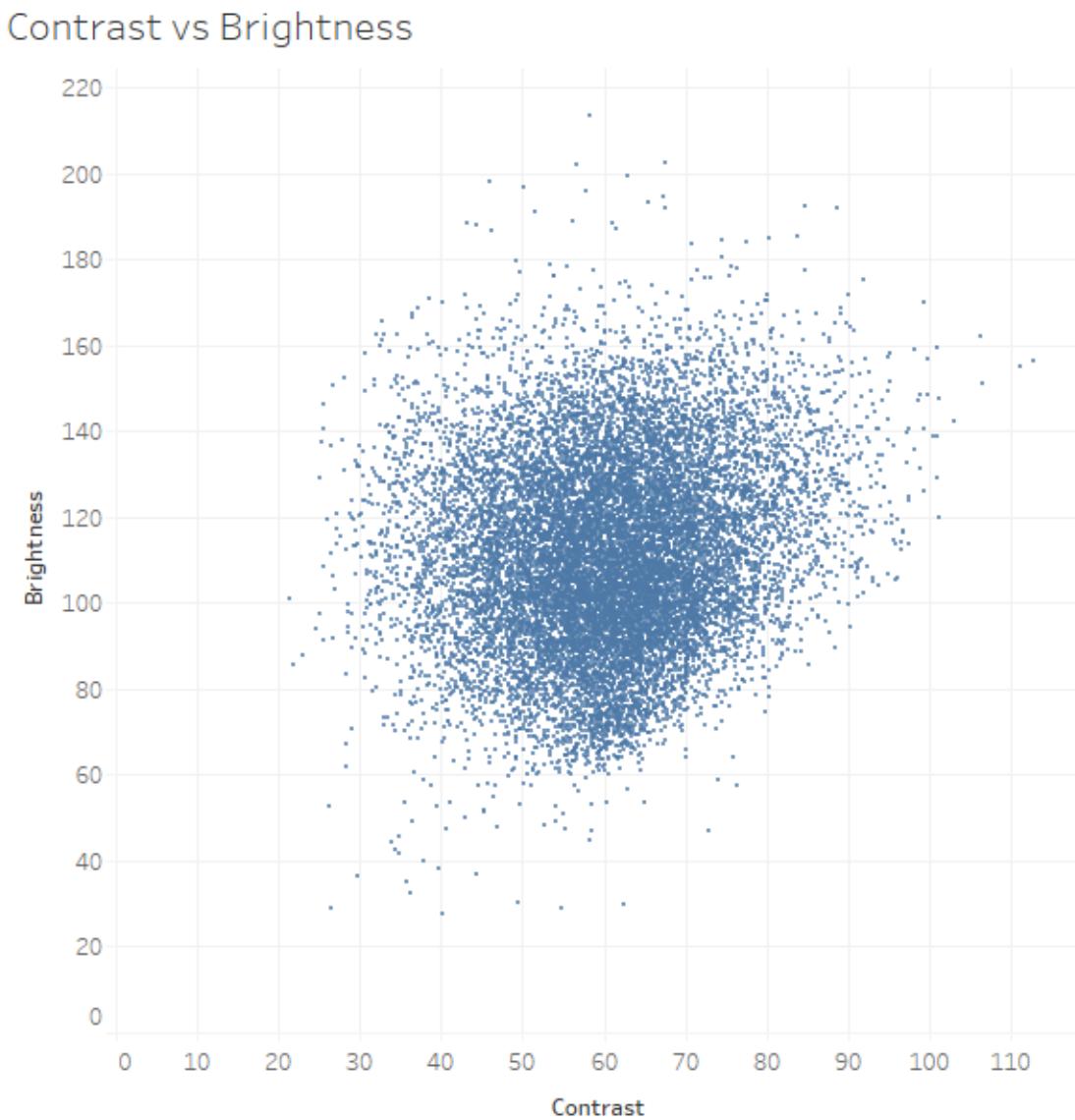
### 1.5.2 Contrast Distribution



The contrast distribution related to each individual file, showing the range of contrast values across the dataset.

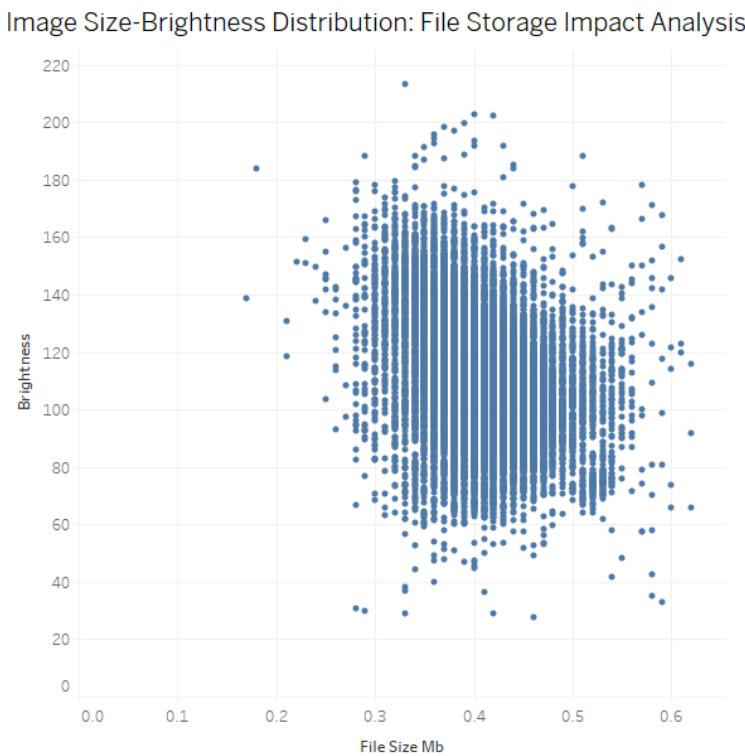
### 1.5.3 Contrast vs Brightness

---



The contrast values are distributed across the dataset, showing the relationship between brightness levels and contrast values.

#### 1.5.4 Brightness related to file size



The contrast values are distributed across the dataset, showing the relationship between brightness levels and file sizes.

```
[12]: class ImageProcessor:  
    def __init__(self, img_size: Tuple[int, int] = (224, 224)):  
        self.img_size = img_size  
  
    @tf.function  
    def _decode_img(self, img_path: str) -> tf.Tensor:  
        """  
        Decodes the image from the specified file path.  
  
        Args:  
            img_path (str): The file path of the image.  
  
        Returns:  
            tf.Tensor: The decoded image  
        """  
  
        with tf.device("/cpu:0"):  
            img_raw = tf.io.read_file(img_path)  
            img = tf.image.decode_png(img_raw, channels=3)
```

```

        img = tf.cast(img, tf.float32)
        img = tf.image.resize(img, self.img_size)

        img = img / 255.0
        return img

    def load_and_preprocess(
        self, image_path: str, label: int
    ) -> Tuple[tf.Tensor, tf.Tensor]:
        """
        Loads and preprocesses the image from the specified file path.

        Args:
            image_path (str): The file path of the image.
            label (int): The label of the image.

        Returns:
            Tuple[tf.Tensor, tf.Tensor]: The preprocessed image and label.
        """

        image = self._decode_img(image_path)
        return image, label

    @tf.function
    def augment_image(
        self, image: tf.Tensor, label: tf.Tensor
    ) -> Tuple[tf.Tensor, tf.Tensor]:
        """
        Applies data augmentation to the input image. Applies random flips,
        brightness, and contrast adjustments.

        Args:
            image (tf.Tensor): The input image.
            label (tf.Tensor): The label of the image.

        Returns:
            Tuple[tf.Tensor, tf.Tensor]: The augmented image and label.
        """

        image = tf.image.random_flip_left_right(image)
        image = tf.image.random_brightness(image, max_delta=0.2)
        image = tf.image.random_contrast(image, lower=0.8, upper=1.2)
        image = tf.clip_by_value(image, 0, 1)

        return image, label

```

**3.3 TFDatasetBuilder Class** The TFDatasetBuilder class converts image data loaded by the SparkDataLoader into TensorFlow datasets for model training. It handles batching, shuffling, and prefetching to optimize data loading and training performance.

```
[13]: from typing import Optional, Union
```

```
[14]: class TFDatasetBuilder:
    def __init__(self, image_processor: ImageProcessor):
        self.image_processor = image_processor

    def create_dataset(
        self,
        spark_df: Union[DataFrame, pd.DataFrame],
        batch_size: int = 32,
        augment: bool = False,
        shuffle: bool = True,
        buffer_size: int = 1000,
    ) -> tf.data.Dataset:
        """
        Creates a TensorFlow Dataset from the input Spark DataFrame.

        Args:
            spark_df: Union[DataFrame, pd.DataFrame] - The input DataFrame containing the image paths and labels.
            batch_size: int - The batch size for the dataset.
            augment: bool - Whether to apply data augmentation.
            shuffle: bool - Whether to shuffle the dataset.
            buffer_size: int - The buffer size for shuffling.

        Returns:
            tf.data.Dataset - The TensorFlow Dataset containing the images and labels.
        """
        if hasattr(spark_df, "toPandas"):
            pd_df = spark_df.toPandas()

        else:
            pd_df = spark_df

        required_columns = ["image_path", "label_index"]
        missing_columns = [col for col in required_columns if col not in pd_df.columns]
        if missing_columns:
            raise ValueError(f"Missing required columns: {missing_columns}")

        try:
```

```

pd_df["label_index"] = pd_df["label_index"].astype("int32")
dataset = tf.data.Dataset.from_tensor_slices(
    (pd_df["image_path"].values, pd_df["label_index"].values)
)

if shuffle:
    dataset = dataset.shuffle(buffer_size, reshuffle_each_iteration=True)

dataset = dataset.map(
    self.image_processor.load_and_preprocess,
    num_parallel_calls=tf.data.AUTOTUNE,
)

if augment:
    dataset = dataset.map(
        self.image_processor.augment_image,
        num_parallel_calls=tf.data.AUTOTUNE,
    )

dataset = dataset.batch(batch_size)
dataset = dataset.prefetch(tf.data.AUTOTUNE)

return dataset

except Exception as e:
    raise ValueError(f"Error creating dataset: {e}")

```

## 1.6 4. Model Architecture

### 1.6.1 4.1 Tensorflow Model

Creates a ResNet50V2-based model for image classification, with the following architecture:

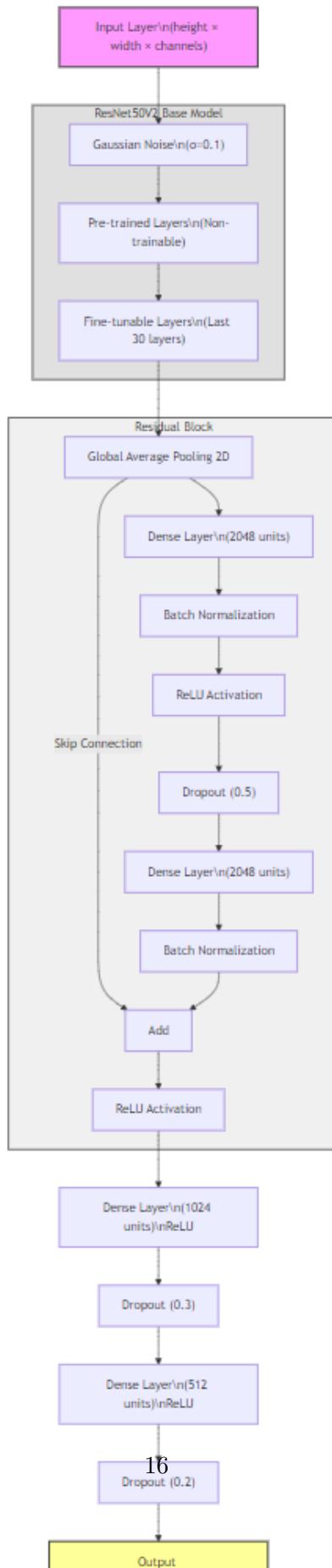
- Pre-trained ResNet50V2 backbone
- Global Average Pooling layer
- Dense layer with 64 output classes
- Softmax activation for multi-class classification

### 1.6.2 4.2 Model Callbacks

- `ModelCheckpoint`: saves the best model during training.
- `EarlyStopping`: stops training if the validation loss does not improve.
- `ReduceLRonPlateau`: reduces learning rate if the validation loss plateaus.
- `TensorBoard`: logs training metrics for visualization.



### 1.6.3 4.3 Model Diagram



#### 1.6.4 4.4 PySparkML Model

The PySparkML model is a simple logistic regression classifier that uses the extracted features from the pre-trained ResNet50V2 model as input. This model is used for inference on large-scale datasets where the deep learning model is not feasible due to computational constraints.

```
[15]: class ModelBuilder:
    @staticmethod
    def build_model(
        input_shape: Tuple[int, int, int], num_classes: int
    ) -> tf.keras.Model:
        """
        Builds an image classification model.

        Args:
            input_shape: Input image dimensions (height, width, channels)
            num_classes: Number of output classes
        """

        base_model = tf.keras.applications.ResNet50V2(
            weights="imagenet", include_top=False, input_shape=input_shape
        )

        for layer in base_model.layers[-30:]:
            layer.trainable = True

        for layer in base_model.layers[:-30]:
            layer.trainable = False

        inputs = tf.keras.layers.Input(shape=input_shape)
        x = tf.keras.layers.GaussianNoise(0.1)(inputs)
        x = base_model(x)
        x = tf.keras.layers.GlobalAveragePooling2D()(x)

        residual = x
        x = tf.keras.layers.Dense(2048, use_bias=False)(x)
        x = tf.keras.layers.BatchNormalization()(x)
        x = tf.keras.layers.Activation("relu")(x)
        x = tf.keras.layers.Dropout(0.5)(x)
        x = tf.keras.layers.Dense(2048, use_bias=False)(x)
        x = tf.keras.layers.BatchNormalization()(x)
        x = tf.keras.layers.Add()([x, residual])
        x = tf.keras.layers.Activation("relu")(x)

        x = tf.keras.layers.Dense(1024, activation="relu")(x)
        x = tf.keras.layers.Dropout(0.3)(x)
        x = tf.keras.layers.Dense(512, activation="relu")(x)
        x = tf.keras.layers.Dropout(0.2)(x)
```

```

        outputs = tf.keras.layers.Dense(num_classes, activation="softmax")(x)

    return tf.keras.Model(inputs=inputs, outputs=outputs)

```

[16]: from typing import List

```

[17]: class TrainingManager:
    @staticmethod
    def get_callbacks(
        checkpoint_path: str, tensorboard_dir: Optional[str] = None
    ) -> List[tf.keras.callbacks.Callback]:
        """
        Creates a list of callbacks for the model training.

        Args:
            checkpoint_path: str - The path to save the model checkpoints.
            tensorboard_dir: Optional[str] - The directory for TensorBoard logs.

        Returns:
            List[tf.keras.callbacks.Callback] - A list of Keras callbacks.
        """

        callbacks = [
            tf.keras.callbacks.ModelCheckpoint(
                checkpoint_path,
                monitor="val_accuracy",
                mode="max",
                save_best_only=True,
                verbose=1,
            ),
            tf.keras.callbacks.EarlyStopping(
                monitor="val_accuracy", mode="max", patience=10, verbose=1
            ),
            tf.keras.callbacks.ReduceLROnPlateau(
                monitor="val_accuracy",
                mode="max",
                factor=0.5,
                patience=5,
                min_lr=1e-7,
                verbose=1,
            ),
        ]
        if tensorboard_dir:
            callbacks.append(
                tf.keras.callbacks.TensorBoard(
                    log_dir=tensorboard_dir, histogram_freq=1
                )
            )
        return callbacks

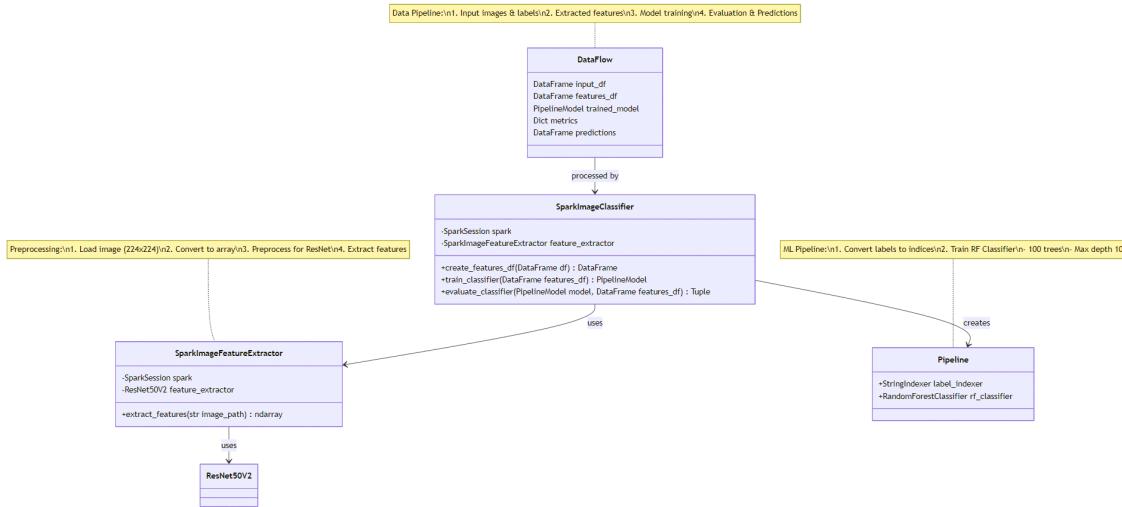
```

```

        )
    )

return callbacks

```



## PySpark ML Model

```
[18]: from pyspark.ml import Pipeline
from pyspark.ml.feature import StringIndexer
from pyspark.ml.classification import RandomForestClassifier
from pyspark.ml.evaluation import MulticlassClassificationEvaluator
from pyspark.sql.types import StructType, StructField, StringType
from pyspark.ml.linalg import Vectors, VectorUDT
```

```
[19]: class SparkImageFeatureExtractor:
    def __init__(self, spark_session):
        self.spark = spark_session
        self.feature_extractor = tf.keras.applications.ResNet50V2(
            include_top=False, weights="imagenet", pooling="avg"
        )

    def extract_features(self, image_path: str) -> np.ndarray:
        """
        Extracts the features from the images using a pre-trained ResNet50V2 model.
        """

        Args:
            image_path: str - The path to the image file.

        Returns:
```

```

    np.ndarray - The extracted features from the image.
"""

try:
    img = tf.keras.preprocessing.image.load_img(
        image_path, target_size=(224, 224)
    )

    x = tf.keras.preprocessing.image.img_to_array(img)
    x = tf.keras.applications.resnet_v2.preprocess_input(x)
    x = np.expand_dims(x, axis=0)

    features = self.feature_extractor.predict(x)
    return features.flatten()

except Exception as e:
    print(f"Error processing {image_path}: {str(e)}")
    return None

```

```

[20]: class SparkImageClassifier:
    def __init__(self, spark_session):
        self.spark = spark_session
        self.feature_extractor = SparkImageFeatureExtractor(spark_session)

    def create_features_df(self, df):
        """
        Creates a DataFrame containing the image features.

        Args:
            df: DataFrame - The input DataFrame containing the image paths and
        ↪labels.

        Returns:
            DataFrame - A DataFrame containing the image paths, labels, and
        ↪features.
        """

        features_list = []

        if hasattr(df, "collect"):
            rows = df.collect()

        else:
            rows = df.to_dict("records")

        for idx, row in enumerate(rows):
            image_path = row["image_path"]
            label = row["label"]

```

```

try:
    features = self.feature_extractor.extract_features(image_path)

    if features is not None:
        vector = Vectors.dense(features)
        features_list.append((image_path, label, vector))

except Exception as e:
    print(f"Error processing {image_path}: {str(e)}")
    continue

schema = StructType(
[
    StructField("image_path", StringType(), True),
    StructField("label", StringType(), True),
    StructField("features", VectorUDT(), True),
]
)
)

return self.spark.createDataFrame(features_list, schema=schema)

def train_classifier(self, features_df):
    """
    Trains a Random Forest classifier using the extracted image features.

    Args:
        features_df: DataFrame - The DataFrame containing the image paths, labels, and features.

    Returns:
        PipelineModel - A trained Spark ML Pipeline model.
    """

pipeline = Pipeline(
    stages=[
        StringIndexer(inputCol="label", outputCol="label_index"),
        RandomForestClassifier(
            labelCol="label_index",
            featuresCol="features",
            numTrees=100,
            maxDepth=10,
        ),
    ]
)

model = pipeline.fit(features_df)

```

```

    return model

def evaluate_classifier(self, model, features_df):
    """
    Evaluates the trained classifier using the test features.

    Args:
        model: PipelineModel - The trained Spark ML Pipeline model.
        features_df: DataFrame - The DataFrame containing the test features.

    Returns:
        Tuple[Dict[str, float], DataFrame] - A tuple containing the evaluation metrics and predictions.
    """
    test_features = self.create_features_df(features_df)
    predictions = model.transform(test_features)

    evaluator = MulticlassClassificationEvaluator(
        labelCol="label_index", predictionCol="prediction"
    )

    metrics = {}
    for metric in ["accuracy", "weightedPrecision", "weightedRecall", "f1"]:
        evaluator.setMetricName(metric)
        metrics[metric] = evaluator.evaluate(predictions)

    return metrics, predictions

```

## 1.7 5. ModelEvaluator Class

The ModelEvaluator class is a utility for evaluating machine learning model predictions. It provides methods for calculating classification metrics such as accuracy, precision, recall, and F1 score. Additionally, it supports generating classification reports and confusion matrices for detailed analysis of model performance.

```
[21]: from pyspark.ml.evaluation import MulticlassClassificationEvaluator
```

```
[22]: class ModelEvaluator:
    def __init__(self, spark, label_to_index: dict):
        self.spark = spark
        self.label_to_index = label_to_index
        self.index_to_label = {v: k for k, v in label_to_index.items()}

    def create_prediction_dataframe(
        self,
        true_labels: np.ndarray,
```

```

    predictions: np.ndarray,
) -> DataFrame:
    """
    Convert numpy arrays to PySpark dataframe for evaluation.

    Args:
        true_labels: np.ndarray - The true labels.
        predictions: np.ndarray - The predicted labels.

    Returns:
        DataFrame - A PySpark DataFrame containing the true and predicted
        labels.
    """

    pred_labels = np.argmax(predictions, axis=1)
    pdf = pd.DataFrame(
        {
            "label": true_labels.astype("double"),
            "prediction": pred_labels.astype("double"),
            "probability": [p.tolist() for p in predictions],
        }
    )

    return self.spark.createDataFrame(pdf)

def evaluate_model(
    self,
    true_labels: np.ndarray,
    predictions: np.ndarray,
) -> dict:
    """
    Evaluate model using various PySpark metrics.

    Returns:
        Dictionary containing all evaluation metrics
    """

    pred_df = self.create_prediction_dataframe(true_labels, predictions)
    evaluator = MulticlassClassificationEvaluator(
        labelCol="label", predictionCol="prediction",
        probabilityCol="probability"
    )

    metrics = {}

    metrics["accuracy"] = evaluator.setMetricName("accuracy").
    evaluate(pred_df)
    metrics["weighted_precision"] = evaluator.setMetricName(

```

```

        "weightedPrecision"
    ).evaluate(pred_df)

    metrics["weighted_recall"] = evaluator.setMetricName("weightedRecall").
evaluate(
    pred_df
)

    metrics["weighted_f1"] = evaluator.setMetricName("weightedFMeasure").
evaluate(
    pred_df
)

    class_metrics = self._calculate_per_class_metrics(pred_df)
metrics["per_class_metrics"] = class_metrics

    return metrics

def _calculate_per_class_metrics(self, pred_df):
    confusion_matrix = pred_df.groupBy("label", "prediction").count()
    cm_pd = confusion_matrix.toPandas()
    class_metrics = {}

    for class_idx in self.label_to_index.values():
        tp = cm_pd[
            (cm_pd["label"] == class_idx) & (cm_pd["prediction"] ==_
class_idx)
        ]["count"].sum()

        fp = cm_pd[
            (cm_pd["label"] != class_idx) & (cm_pd["prediction"] ==_
class_idx)
        ]["count"].sum()

        fn = cm_pd[
            (cm_pd["label"] == class_idx) & (cm_pd["prediction"] !=_
class_idx)
        ]["count"].sum()

        # Calculate metrics
        precision = tp / (tp + fp) if (tp + fp) > 0 else 0
        recall = tp / (tp + fn) if (tp + fn) > 0 else 0
        f1 = (
            2 * (precision * recall) / (precision + recall)
            if (precision + recall) > 0
            else 0
        )

```

```

        class_name = self.index_to_label[class_idx]
        class_metrics[class_name] = {
            "precision": precision,
            "recall": recall,
            "f1_score": f1,
            "support": tp + fn,
        }

    return class_metrics

def print_evaluation_report(self, metrics: dict) -> None:
    print("\nModel Evaluation Report")
    print("=" * 80)

    print("\nOverall Metrics:")
    print(f"Accuracy: {metrics['accuracy']:.4f}")
    print(f"Weighted Precision: {metrics['weighted_precision']:.4f}")
    print(f"Weighted Recall: {metrics['weighted_recall']:.4f}")
    print(f"Weighted F1: {metrics['weighted_f1']:.4f}")

    print("\nPer-class Metrics:")
    print("-" * 80)
    print(
        f"{'Class':<20} {'Precision':>10} {'Recall':>10} {'F1-Score':>10}{'Support':>10}"
    )
    print("-" * 80)

    for class_name, class_metrics in metrics["per_class_metrics"].items():
        print(
            f"{class_name:<20} "
            f"{class_metrics['precision']:>10.4f} "
            f"{class_metrics['recall']:>10.4f} "
            f"{class_metrics['f1_score']:>10.4f} "
            f"{class_metrics['support']:>10d}"
        )

```

[23]: def evaluate\_model\_performance(model, test\_dataset, spark, label\_to\_index):  
 """

*Evaluate the model performance using the test dataset.*

*Args:*

*model: The trained model to evaluate.  
 test\_dataset: The test dataset to evaluate the model on.  
 spark: The SparkSession object.  
 label\_to\_index: The label to index mapping.*

```

>Returns:
    dict: A dictionary containing the evaluation metrics.
"""

evaluator = ModelEvaluator(spark, label_to_index)
test_images, test_labels = [], []

for images, labels in test_dataset:
    test_images.extend(images.numpy())
    test_labels.extend(labels.numpy())

predictions = model.predict(np.array(test_images))
metrics = evaluator.evaluate_model(np.array(test_labels), predictions)
evaluator.print_evaluation_report(metrics)

return metrics

```

## 1.8 6. Data Visualization

### 1.8.1 6.1 Confusion Matrix

Generates a confusion matrix to visualize the model's performance across different classes based off the error rate.

### 1.8.2 6.2 Plot training history

Plots the training and validation loss and accuracy over epochs to visualize the model's learning process.

```
[24]: import matplotlib.pyplot as plt
import seaborn as sns
import numpy as np
from sklearn.metrics import confusion_matrix
```

```
[25]: class VisualizationManager:
    def __init__(self, label_to_index: Dict[str, int]):
        self.label_to_index = label_to_index
        self.index_to_label = {v: k for k, v in label_to_index.items()}

    def plot_confusion_matrix(
        self,
        true_labels: np.ndarray,
        pred_labels: np.ndarray,
        min_errors: int = 1,
        figsize: tuple = (12, 8),
    ) -> None:
        """
```

*Plot confusion matrix using seaborn.*

*Args:*

```
    true_labels: Ground truth labels
    pred_labels: Predicted labels
    normalize: Whether to normalize the confusion matrix
    figsize: Figure size (width, height)
    """
    cm = confusion_matrix(true_labels, pred_labels)
    cm_norm = cm.astype("float") / cm.sum(axis=1)[:, np.newaxis]

    labels = list(self.label_to_index.keys())
    error_mask = np.zeros_like(cm, dtype=bool)
    for i in range(len(cm)):
        for j in range(len(cm)):
            if i != j and cm[i, j] > min_errors:
                error_mask[i, j] = True

    if np.any(error_mask):
        rows_with_errors = np.any(error_mask, axis=1)
        cols_with_errors = np.any(error_mask, axis=0)

        cm_filtered = cm[rows_with_errors][:, cols_with_errors]
        cm_norm_filtered = cm_norm[rows_with_errors][:, cols_with_errors]
        labels_filtered = [labels[i] for i, v in
                           enumerate(rows_with_errors) if v]

        plt.figure(figsize=figsize)
        sns.heatmap(
            cm_norm_filtered,
            annot=cm_filtered,
            fmt="g",
            cmap="Blues",
            xticklabels=[
                labels[i] for i in range(len(labels)) if cols_with_errors[i]
            ],
            yticklabels=labels_filtered,
            cbar_kws={"label": "Normalized Confusion"},
        )

        plt.title("Confusion Matrix (Showing Only Errors)", pad=20)
        plt.xlabel("Predicted Label")
        plt.ylabel("True Label")

        plt.xticks(rotation=45, ha="right")
        plt.yticks(rotation=0)
```

```

        plt.tight_layout()

    else:
        plt.figure(figsize=figsize)
        sns.heatmap(
            cm_norm,
            annot=True,
            fmt=".2%",
            cmap="Blues",
            xticklabels=labels,
            yticklabels=labels,
        )

        plt.title("Confusion Matrix (Perfect Accuracy!)")
        plt.xlabel("Predicted Label")
        plt.ylabel("True Label")
        plt.xticks(rotation=45, ha="right")
        plt.tight_layout()

    def plot_training_history(self, history: "tf.keras.callbacks.History") ->_
        None:
        """
        Plot training history using matplotlib (more stable than plotly).

        Args:
            history: Training history from model.fit()
        """
        fig, ax1 = plt.subplots(figsize=(12, 6))

        color = "tab:blue"
        ax1.set_xlabel("Epoch")
        ax1.set_ylabel("Loss", color=color)
        ax1.plot(history.history["loss"], color=color, label="Train Loss")
        ax1.plot(history.history["val_loss"], color="tab:cyan", label="Val_"
        Loss)
        ax1.tick_params(axis="y", labelcolor=color)

        ax2 = ax1.twinx()
        color = "tab:orange"
        ax2.set_ylabel("Accuracy", color=color)
        ax2.plot(history.history["accuracy"], color=color, label="Train Acc")
        ax2.plot(history.history["val_accuracy"], color="tab:red", label="Val_"
        Acc)
        ax2.tick_params(axis="y", labelcolor=color)

        plt.title("Training History")
        lines1, labels1 = ax1.get_legend_handles_labels()

```

```

lines2, labels2 = ax2.get_legend_handles_labels()
ax2.legend(lines1 + lines2, labels1 + labels2, loc="center right")

plt.tight_layout()
plt.show()

print("\nFinal Metrics:")
print(f"Train Loss: {history.history['loss'][-1]:.4f}")
print(f"Val Loss: {history.history['val_loss'][-1]:.4f}")
print(f"Train Accuracy: {history.history['accuracy'][-1]:.4f}")
print(f"Val Accuracy: {history.history['val_accuracy'][-1]:.4f}")

def plot_sample_predictions(
    self,
    images: np.ndarray,
    true_labels: np.ndarray,
    pred_labels: np.ndarray,
    confidences: np.ndarray,
    num_samples: int = 16,
) -> None:
    """
    Plot sample predictions with their true labels and confidence scores.
    """

    Args:
        images: Array of images
        true_labels: True label indices
        pred_labels: Predicted label indices
        confidences: Prediction confidences
        num_samples: Number of samples to plot
    """

    indices = np.random.choice(
        len(images), min(num_samples, len(images)), replace=False
    )

    grid_size = int(np.ceil(np.sqrt(num_samples)))
    fig = plt.figure(figsize=(15, 15))

    for idx, i in enumerate(indices):
        ax = plt.subplot(grid_size, grid_size, idx + 1)

        plt.imshow(images[i])
        plt.axis("off")

        true_label = self.index_to_label[true_labels[i]]
        pred_label = self.index_to_label[pred_labels[i]]
        confidence = confidences[i] * 100

```

```

        color = "green" if true_label == pred_label else "red"
        title = f"True: {true_label}\nPred: {pred_label}\n{confidence:.1f}%" 
        ax.set_title(title, color=color, fontsize=8)

    plt.tight_layout()
    plt.show()

```

## 1.9 Main Execution

[26]: data\_loader = SparkDataLoader(spark)

[27]: image\_preprocessor = ImageProcessor()
dataset\_builder = TFDataSetBuilder(image\_preprocessor)

[28]: data\_splitter = DatasetSplitter()
model\_builder = ModelBuilder()
training\_manager = TrainingManager()

[29]: df = data\_loader.load\_from\_directory("../data/images/")

Found 14377 images in /home/carlos/developer/concentracion-AI/big\_data/data/images

[30]: label\_to\_index, index\_to\_label = data\_loader.create\_label\_mappings(df)

[31]: df = data\_loader.add\_label\_indices(df, label\_to\_index)
df.printSchema()

```

root
|-- image_path: string (nullable = true)
|-- label: string (nullable = true)
|-- label_index: integer (nullable = true)

```

[32]: df.show(5)

image_path	label	label_index
/home/carlos/deve...	cheetah	10

only showing top 5 rows

```
[33]: df.count()
```

```
[33]: 14377
```

### 1.9.1 Splitting the data

```
[34]: train_df, val_df, test_df = data_splitter.split_spark_data(  
    df, train_ratio=0.7, val_ratio=0.15  
)
```

```
[35]: train_dataset = dataset_builder.create_dataset(  
    train_df, batch_size=16, augment=True, shuffle=True  
)  
  
val_dataset = dataset_builder.create_dataset(val_df, batch_size=16, □  
    ↵shuffle=False)  
  
test_dataset = dataset_builder.create_dataset(test_df, batch_size=16, □  
    ↵shuffle=False)
```

```
I0000 00:00:1732324060.743044 167592 gpu_device.cc:2022] Created device  
/job:localhost/replica:0/task:0/device:GPU:0 with 3586 MB memory: -> device: 0,  
name: NVIDIA GeForce RTX 3060 Laptop GPU, pci bus id: 0000:01:00.0, compute  
capability: 8.6
```

### 1.9.2 Tensorflow Model

```
[36]: model = model_builder.build_model(  
    input_shape=(224, 224, 3), num_classes=len(label_to_index)  
)
```

```
[37]: model.compile(  
    optimizer=tf.keras.optimizers.Adam(learning_rate=1e-4),  
    loss=tf.keras.losses.SparseCategoricalCrossentropy(),  
    metrics=["accuracy"],  
)
```

```
[38]: model.summary()
```

```
Model: "functional"
```

Layer (type)	Output Shape	Param #	Connected to
input_layer_1 (InputLayer)	(None, 224, 224, 3)	0	-
cast_1 (Cast)	(None, 224, 224, 1)	0	input_layer_1[0]...

	3)		
gaussian_noise ( <a href="#">GaussianNoise</a> )	(None, 224, 224, 3)	0	cast_1[0] [0]
resnet50v2 ( <a href="#">Functional</a> )	(None, 7, 7, 2048)	23,564,800	gaussian_noise[0...]
global_average_poo... ( <a href="#">GlobalAveragePool...</a> )	(None, 2048)	0	resnet50v2[0] [0]
dense ( <a href="#">Dense</a> )	(None, 2048)	4,194,304	global_average_p...
batch_normalization ( <a href="#">BatchNormalizatio...</a> )	(None, 2048)	8,192	dense[0] [0]
activation ( <a href="#">Activation</a> )	(None, 2048)	0	batch_normalizat...
dropout ( <a href="#">Dropout</a> )	(None, 2048)	0	activation[0] [0]
dense_1 ( <a href="#">Dense</a> )	(None, 2048)	4,194,304	dropout[0] [0]
batch_normalizatio... ( <a href="#">BatchNormalizatio...</a> )	(None, 2048)	8,192	dense_1[0] [0]
add ( <a href="#">Add</a> )	(None, 2048)	0	batch_normalizat... global_average_p...
activation_1 ( <a href="#">Activation</a> )	(None, 2048)	0	add[0] [0]
dense_2 ( <a href="#">Dense</a> )	(None, 1024)	2,098,176	activation_1[0] [...]
dropout_1 ( <a href="#">Dropout</a> )	(None, 1024)	0	dense_2[0] [0]
dense_3 ( <a href="#">Dense</a> )	(None, 512)	524,800	dropout_1[0] [0]
dropout_2 ( <a href="#">Dropout</a> )	(None, 512)	0	dense_3[0] [0]
dense_4 ( <a href="#">Dense</a> )	(None, 64)	32,832	dropout_2[0] [0]

Total params: 34,625,600 (132.09 MB)

Trainable params: 25,496,128 (97.26 MB)

Non-trainable params: 9,129,472 (34.83 MB)

```
[39]: callbacks = training_manager.get_callbacks(
    checkpoint_path="best_model.keras", tensorboard_dir="./logs"
)
```

## Training

```
[40]: history = model.fit(
    train_dataset,
    validation_data=val_dataset,
    epochs=30,
    callbacks=callbacks,
)
```

Epoch 1/30

```
WARNING: All log messages before absl::InitializeLog() is called are written to
STDERR
I0000 00:00:1732324079.673635 168500 service.cc:148] XLA service 0x7f5c5c014fc0
initialized for platform CUDA (this does not guarantee that XLA will be used).
Devices:
I0000 00:00:1732324079.673681 168500 service.cc:156] StreamExecutor device
(0): NVIDIA GeForce RTX 3060 Laptop GPU, Compute Capability 8.6
2024-11-22 19:07:59.882533: I
tensorflow/compiler/mlir/tensorflow/utils/dump_mlir_util.cc:268] disabling MLIR
crash reproducer, set env var `MLIR_CRASH_REPRODUCER_DIRECTORY` to enable.
I0000 00:00:1732324080.940967 168500 cuda_dnn.cc:529] Loaded cuDNN version
90300
2024-11-22 19:08:02.031977: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_7696', 12 bytes spill stores, 12 bytes spill loads

I0000 00:00:1732324091.692315 168500 device_compiler.h:188] Compiled cluster
using XLA! This line is logged at most once for the lifetime of the process.

629/629          0s 52ms/step -
accuracy: 0.5722 - loss: 1.8919

2024-11-22 19:08:46.406595: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1715', 8 bytes spill stores, 8 bytes spill loads

2024-11-22 19:08:46.437417: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1715', 12 bytes spill stores, 12 bytes spill loads
```

```
2024-11-22 19:08:46.463652: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1726', 12 bytes spill stores, 12 bytes spill loads

2024-11-22 19:08:46.721013: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1726', 8 bytes spill stores, 8 bytes spill loads

2024-11-22 19:08:47.160300: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1738', 12 bytes spill stores, 12 bytes spill loads

2024-11-22 19:08:47.455233: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1745', 12 bytes spill stores, 12 bytes spill loads

2024-11-22 19:08:47.455338: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1738', 12 bytes spill stores, 12 bytes spill loads

2024-11-22 19:08:47.497106: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1752', 4 bytes spill stores, 4 bytes spill loads

2024-11-22 19:08:47.568434: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1752', 8 bytes spill stores, 8 bytes spill loads

2024-11-22 19:08:47.749316: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1745', 12 bytes spill stores, 12 bytes spill loads

2024-11-22 19:08:47.803613: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1752', 12 bytes spill stores, 12 bytes spill loads

2024-11-22 19:08:47.958783: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
```

```
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1752', 4 bytes spill stores, 4 bytes spill loads

2024-11-22 19:08:52.913734: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1738_0', 8 bytes spill stores, 8 bytes spill loads

2024-11-22 19:08:53.240123: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1738', 12 bytes spill stores, 12 bytes spill loads

2024-11-22 19:08:53.298700: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1715', 8 bytes spill stores, 8 bytes spill loads

2024-11-22 19:08:53.378429: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1726', 308 bytes spill stores, 316 bytes spill loads

2024-11-22 19:08:53.472200: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1715', 12 bytes spill stores, 12 bytes spill loads

2024-11-22 19:08:53.584842: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1738', 304 bytes spill stores, 304 bytes spill loads

2024-11-22 19:08:53.709848: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1726', 12 bytes spill stores, 12 bytes spill loads

2024-11-22 19:08:54.285050: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1738', 12 bytes spill stores, 12 bytes spill loads

2024-11-22 19:08:54.286017: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1726', 8 bytes spill stores, 8 bytes spill loads
```

```

2024-11-22 19:08:54.319656: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1745', 12 bytes spill stores, 12 bytes spill loads

2024-11-22 19:08:54.604343: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1745', 12 bytes spill stores, 12 bytes spill loads

2024-11-22 19:08:54.812110: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1752', 8 bytes spill stores, 8 bytes spill loads

2024-11-22 19:08:54.812190: I
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas
warning : Registers are spilled to local memory in function
'gemm_fusion_dot_1752', 4 bytes spill stores, 4 bytes spill loads

```

```

Epoch 1: val_accuracy improved from -inf to 0.97124, saving model to
best_model.keras
629/629          73s 82ms/step -
accuracy: 0.5726 - loss: 1.8902 - val_accuracy: 0.9712 - val_loss: 0.1153 -
learning_rate: 1.0000e-04
Epoch 2/30
628/629          0s 35ms/step -
accuracy: 0.9620 - loss: 0.1506
Epoch 2: val_accuracy improved from 0.97124 to 0.99072, saving model to
best_model.keras
629/629          28s 45ms/step -
accuracy: 0.9620 - loss: 0.1505 - val_accuracy: 0.9907 - val_loss: 0.0271 -
learning_rate: 1.0000e-04
Epoch 3/30
628/629          0s 29ms/step -
accuracy: 0.9753 - loss: 0.0921
Epoch 3: val_accuracy did not improve from 0.99072
629/629          24s 37ms/step -
accuracy: 0.9753 - loss: 0.0920 - val_accuracy: 0.9736 - val_loss: 0.1441 -
learning_rate: 1.0000e-04
Epoch 4/30
628/629          0s 35ms/step -
accuracy: 0.9798 - loss: 0.0927
Epoch 4: val_accuracy did not improve from 0.99072
629/629          27s 43ms/step -
accuracy: 0.9798 - loss: 0.0927 - val_accuracy: 0.9903 - val_loss: 0.0377 -

```

```
learning_rate: 1.0000e-04
Epoch 5/30
628/629          0s 36ms/step -
accuracy: 0.9856 - loss: 0.0544
Epoch 5: val_accuracy did not improve from 0.99072
629/629          28s 44ms/step -
accuracy: 0.9856 - loss: 0.0544 - val_accuracy: 0.9870 - val_loss: 0.0438 -
learning_rate: 1.0000e-04
Epoch 6/30
629/629          0s 36ms/step -
accuracy: 0.9836 - loss: 0.0598
Epoch 6: val_accuracy did not improve from 0.99072
629/629          29s 45ms/step -
accuracy: 0.9836 - loss: 0.0598 - val_accuracy: 0.9722 - val_loss: 0.2045 -
learning_rate: 1.0000e-04
Epoch 7/30
628/629          0s 31ms/step -
accuracy: 0.9805 - loss: 0.0847
Epoch 7: val_accuracy did not improve from 0.99072

Epoch 7: ReduceLROnPlateau reducing learning rate to 4.999999873689376e-05.
629/629          29s 46ms/step -
accuracy: 0.9805 - loss: 0.0846 - val_accuracy: 0.9875 - val_loss: 0.0670 -
learning_rate: 1.0000e-04
Epoch 8/30
628/629          0s 30ms/step -
accuracy: 0.9918 - loss: 0.0277
Epoch 8: val_accuracy improved from 0.99072 to 0.99490, saving model to
best_model.keras
629/629          26s 41ms/step -
accuracy: 0.9919 - loss: 0.0277 - val_accuracy: 0.9949 - val_loss: 0.0238 -
learning_rate: 5.0000e-05
Epoch 9/30
628/629          0s 35ms/step -
accuracy: 0.9980 - loss: 0.0091
Epoch 9: val_accuracy improved from 0.99490 to 0.99629, saving model to
best_model.keras
629/629          30s 47ms/step -
accuracy: 0.9980 - loss: 0.0091 - val_accuracy: 0.9963 - val_loss: 0.0189 -
learning_rate: 5.0000e-05
Epoch 10/30
628/629          0s 35ms/step -
accuracy: 0.9974 - loss: 0.0079
Epoch 10: val_accuracy did not improve from 0.99629
629/629          29s 45ms/step -
accuracy: 0.9974 - loss: 0.0079 - val_accuracy: 0.9930 - val_loss: 0.0324 -
learning_rate: 5.0000e-05
Epoch 11/30
```

```
629/629          0s 34ms/step -
accuracy: 0.9945 - loss: 0.0189
Epoch 11: val_accuracy did not improve from 0.99629
629/629          27s 43ms/step -
accuracy: 0.9945 - loss: 0.0189 - val_accuracy: 0.9930 - val_loss: 0.0288 -
learning_rate: 5.0000e-05
Epoch 12/30
627/629          0s 29ms/step -
accuracy: 0.9971 - loss: 0.0121
Epoch 12: val_accuracy did not improve from 0.99629
629/629          24s 38ms/step -
accuracy: 0.9971 - loss: 0.0121 - val_accuracy: 0.9917 - val_loss: 0.0399 -
learning_rate: 5.0000e-05
Epoch 13/30
627/629          0s 34ms/step -
accuracy: 0.9960 - loss: 0.0153
Epoch 13: val_accuracy did not improve from 0.99629
629/629          27s 43ms/step -
accuracy: 0.9960 - loss: 0.0153 - val_accuracy: 0.9940 - val_loss: 0.0207 -
learning_rate: 5.0000e-05
Epoch 14/30
627/629          0s 34ms/step -
accuracy: 0.9961 - loss: 0.0171
Epoch 14: val_accuracy did not improve from 0.99629

Epoch 14: ReduceLROnPlateau reducing learning rate to 2.499999936844688e-05.
629/629          27s 43ms/step -
accuracy: 0.9961 - loss: 0.0171 - val_accuracy: 0.9944 - val_loss: 0.0278 -
learning_rate: 5.0000e-05
Epoch 15/30
629/629          0s 35ms/step -
accuracy: 0.9976 - loss: 0.0100
Epoch 15: val_accuracy did not improve from 0.99629
629/629          28s 44ms/step -
accuracy: 0.9976 - loss: 0.0100 - val_accuracy: 0.9954 - val_loss: 0.0246 -
learning_rate: 2.5000e-05
Epoch 16/30
628/629          0s 30ms/step -
accuracy: 0.9991 - loss: 0.0037
Epoch 16: val_accuracy did not improve from 0.99629
629/629          28s 44ms/step -
accuracy: 0.9991 - loss: 0.0037 - val_accuracy: 0.9958 - val_loss: 0.0271 -
learning_rate: 2.5000e-05
Epoch 17/30
629/629          0s 31ms/step -
accuracy: 0.9986 - loss: 0.0030
Epoch 17: val_accuracy improved from 0.99629 to 0.99768, saving model to
best_model.keras
```

```
629/629          27s 43ms/step -
accuracy: 0.9986 - loss: 0.0030 - val_accuracy: 0.9977 - val_loss: 0.0214 -
learning_rate: 2.5000e-05
Epoch 18/30
629/629          0s 36ms/step -
accuracy: 0.9994 - loss: 0.0026
Epoch 18: val_accuracy did not improve from 0.99768
629/629          28s 45ms/step -
accuracy: 0.9994 - loss: 0.0026 - val_accuracy: 0.9954 - val_loss: 0.0275 -
learning_rate: 2.5000e-05
Epoch 19/30
627/629          0s 36ms/step -
accuracy: 0.9991 - loss: 0.0036
Epoch 19: val_accuracy did not improve from 0.99768
629/629          28s 45ms/step -
accuracy: 0.9991 - loss: 0.0036 - val_accuracy: 0.9958 - val_loss: 0.0252 -
learning_rate: 2.5000e-05
Epoch 20/30
628/629          0s 29ms/step -
accuracy: 0.9988 - loss: 0.0044
Epoch 20: val_accuracy did not improve from 0.99768
629/629          27s 42ms/step -
accuracy: 0.9988 - loss: 0.0044 - val_accuracy: 0.9944 - val_loss: 0.0205 -
learning_rate: 2.5000e-05
Epoch 21/30
629/629          0s 30ms/step -
accuracy: 0.9984 - loss: 0.0052
Epoch 21: val_accuracy did not improve from 0.99768
629/629          24s 38ms/step -
accuracy: 0.9984 - loss: 0.0052 - val_accuracy: 0.9963 - val_loss: 0.0245 -
learning_rate: 2.5000e-05
Epoch 22/30
629/629          0s 35ms/step -
accuracy: 0.9996 - loss: 0.0021
Epoch 22: val_accuracy did not improve from 0.99768

Epoch 22: ReduceLROnPlateau reducing learning rate to 1.249999968422344e-05.
629/629          27s 43ms/step -
accuracy: 0.9996 - loss: 0.0021 - val_accuracy: 0.9954 - val_loss: 0.0266 -
learning_rate: 2.5000e-05
Epoch 23/30
629/629          0s 35ms/step -
accuracy: 0.9991 - loss: 0.0018
Epoch 23: val_accuracy did not improve from 0.99768
629/629          27s 43ms/step -
accuracy: 0.9991 - loss: 0.0018 - val_accuracy: 0.9954 - val_loss: 0.0323 -
learning_rate: 1.2500e-05
Epoch 24/30
```

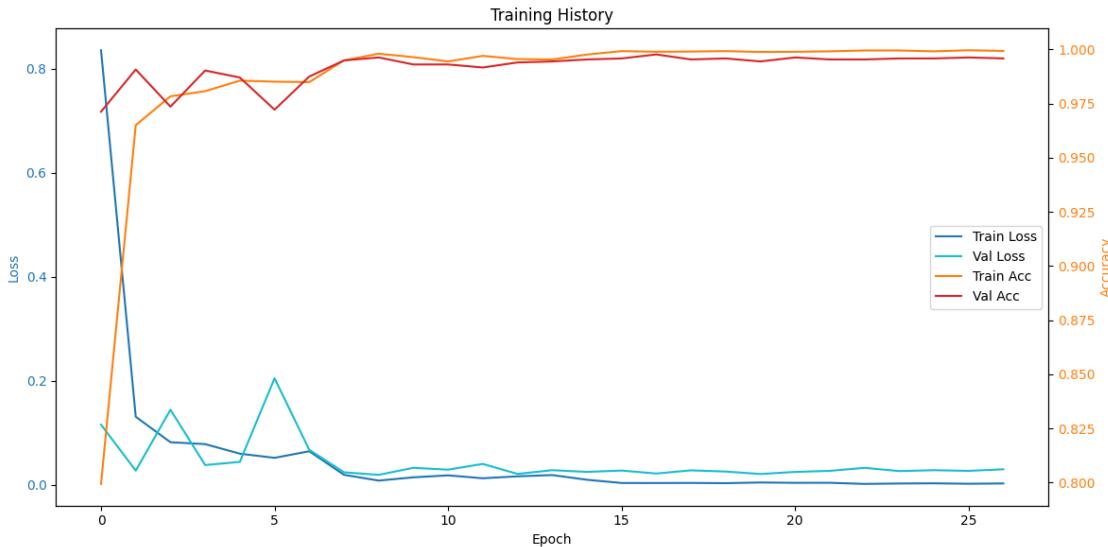
```
628/629          0s 35ms/step -
accuracy: 0.9994 - loss: 0.0023
Epoch 24: val_accuracy did not improve from 0.99768
629/629          31s 49ms/step -
accuracy: 0.9994 - loss: 0.0023 - val_accuracy: 0.9958 - val_loss: 0.0261 -
learning_rate: 1.2500e-05
Epoch 25/30
627/629          0s 31ms/step -
accuracy: 0.9992 - loss: 0.0024
Epoch 25: val_accuracy did not improve from 0.99768
629/629          28s 44ms/step -
accuracy: 0.9992 - loss: 0.0024 - val_accuracy: 0.9958 - val_loss: 0.0278 -
learning_rate: 1.2500e-05
Epoch 26/30
627/629          0s 31ms/step -
accuracy: 0.9998 - loss: 0.0012
Epoch 26: val_accuracy did not improve from 0.99768
629/629          25s 40ms/step -
accuracy: 0.9998 - loss: 0.0012 - val_accuracy: 0.9963 - val_loss: 0.0265 -
learning_rate: 1.2500e-05
Epoch 27/30
627/629          0s 35ms/step -
accuracy: 0.9990 - loss: 0.0031
Epoch 27: val_accuracy did not improve from 0.99768

Epoch 27: ReduceLROnPlateau reducing learning rate to 6.24999984211172e-06.
629/629          27s 44ms/step -
accuracy: 0.9990 - loss: 0.0031 - val_accuracy: 0.9958 - val_loss: 0.0295 -
learning_rate: 1.2500e-05
Epoch 27: early stopping
```

#### Visualize results

```
[41]: viz_manager = VisualizationManager(label_to_index)
```

```
[42]: viz_manager.plot_training_history(history)
```



#### Final Metrics:

```
Train Loss: 0.0024
Val Loss: 0.0295
Train Accuracy: 0.9993
Val Accuracy: 0.9958
```

#### Key Observations

- The loss values (left y-axis) start high around 0.8 and quickly drop within the first few epochs to below 0.2.
- The accuracy values (right y-axis) start low and rapidly improve around 97 to 98% accuracy after the first few epochs.
- After about epoch 10, both metrics stabilize and show only minor improvements.
- Both training and validation metrics improve and converge.
- There's no significant gap between training and validation performance, indicating that the model generalizes well.
- The model reaches stable performance relatively quickly.

```
[43]: test_images, test_labels = [], []
for images, labels in test_dataset:
    test_images.extend(images.numpy())
    test_labels.extend(labels.numpy())

model = tf.keras.models.load_model("best_model.keras")
predictions = model.predict(np.array(test_images))
pred_labels = np.argmax(predictions, axis=1)
```

2024-11-22 19:21:03.660980: I tensorflow/core/framework/local\_rendezvous.cc:405] Local rendezvous is aborting with status: OUT\_OF\_RANGE: End of sequence

2024-11-22 19:21:11.819585: E tensorflow/core/util/util.cc:131] oneDNN supports DT\_HALF only on platforms with AVX-512. Falling back to the default Eigen-based implementation if present.

67/68 0s 19ms/step

2024-11-22 19:21:24.445714: I  
external/local\_xla/xla/stream\_executor/cuda/cuda\_asm\_compiler.cc:397] ptxas warning : Registers are spilled to local memory in function  
'gemm\_fusion\_dot\_1696', 8 bytes spill stores, 8 bytes spill loads

2024-11-22 19:21:24.712476: I  
external/local\_xla/xla/stream\_executor/cuda/cuda\_asm\_compiler.cc:397] ptxas warning : Registers are spilled to local memory in function  
'gemm\_fusion\_dot\_1696', 12 bytes spill stores, 12 bytes spill loads

2024-11-22 19:21:24.797845: I  
external/local\_xla/xla/stream\_executor/cuda/cuda\_asm\_compiler.cc:397] ptxas warning : Registers are spilled to local memory in function  
'gemm\_fusion\_dot\_1707', 8 bytes spill stores, 8 bytes spill loads

2024-11-22 19:21:25.007779: I  
external/local\_xla/xla/stream\_executor/cuda/cuda\_asm\_compiler.cc:397] ptxas warning : Registers are spilled to local memory in function  
'gemm\_fusion\_dot\_1719\_0', 8 bytes spill stores, 8 bytes spill loads

2024-11-22 19:21:25.108575: I  
external/local\_xla/xla/stream\_executor/cuda/cuda\_asm\_compiler.cc:397] ptxas warning : Registers are spilled to local memory in function  
'gemm\_fusion\_dot\_1707', 308 bytes spill stores, 316 bytes spill loads

2024-11-22 19:21:25.317629: I  
external/local\_xla/xla/stream\_executor/cuda/cuda\_asm\_compiler.cc:397] ptxas warning : Registers are spilled to local memory in function  
'gemm\_fusion\_dot\_1707', 12 bytes spill stores, 12 bytes spill loads

2024-11-22 19:21:25.449635: I  
external/local\_xla/xla/stream\_executor/cuda/cuda\_asm\_compiler.cc:397] ptxas warning : Registers are spilled to local memory in function  
'gemm\_fusion\_dot\_1726', 12 bytes spill stores, 12 bytes spill loads

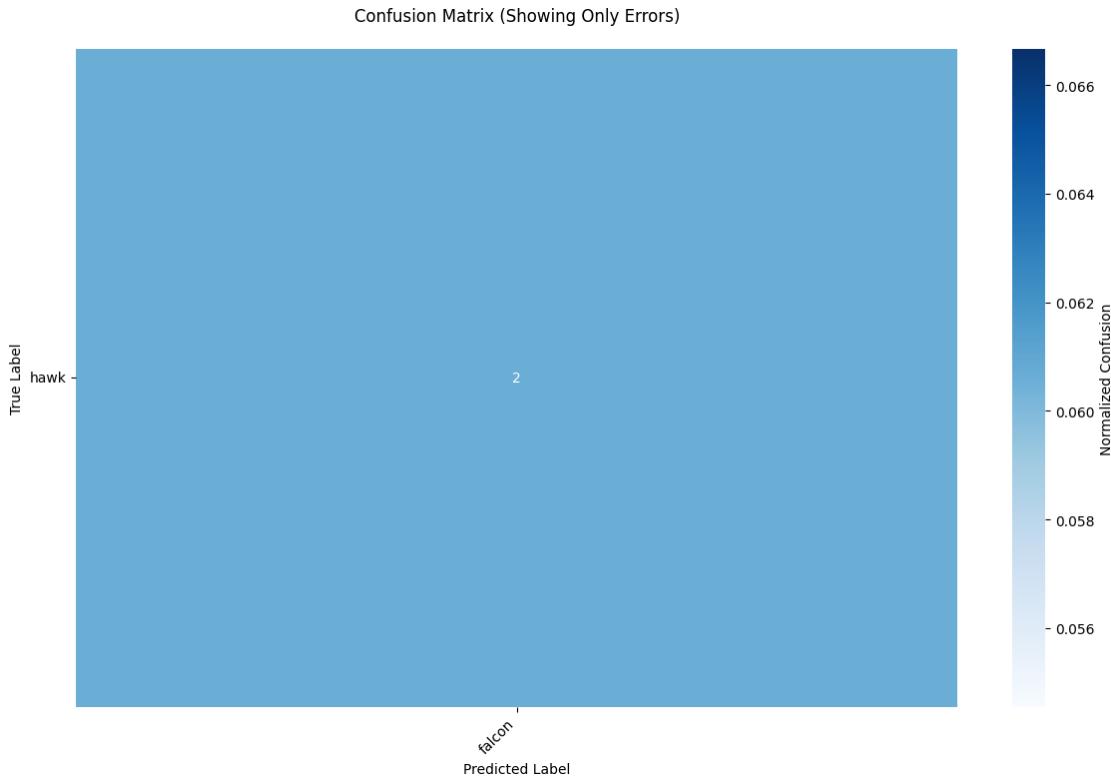
2024-11-22 19:21:25.816317: I  
external/local\_xla/xla/stream\_executor/cuda/cuda\_asm\_compiler.cc:397] ptxas warning : Registers are spilled to local memory in function  
'gemm\_fusion\_dot\_1733', 4 bytes spill stores, 4 bytes spill loads

2024-11-22 19:21:25.826178: I  
external/local\_xla/xla/stream\_executor/cuda/cuda\_asm\_compiler.cc:397] ptxas warning : Registers are spilled to local memory in function

```
'gemm_fusion_dot_1719', 12 bytes spill stores, 12 bytes spill loads  
  
2024-11-22 19:21:26.017868: I  
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas  
warning : Registers are spilled to local memory in function  
'gemm_fusion_dot_1733', 8 bytes spill stores, 8 bytes spill loads  
  
2024-11-22 19:21:26.287777: I  
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas  
warning : Registers are spilled to local memory in function  
'gemm_fusion_dot_1719', 12 bytes spill stores, 12 bytes spill loads  
  
2024-11-22 19:21:26.294322: I  
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas  
warning : Registers are spilled to local memory in function  
'gemm_fusion_dot_1726', 12 bytes spill stores, 12 bytes spill loads  
  
2024-11-22 19:21:26.360981: I  
external/local_xla/xla/stream_executor/cuda/cuda_asm_compiler.cc:397] ptxas  
warning : Registers are spilled to local memory in function  
'gemm_fusion_dot_1719', 304 bytes spill stores, 304 bytes spill loads
```

68/68                  20s 149ms/step

[44]: viz\_manager.plot\_confusion\_matrix(test\_labels, pred\_labels, min\_errors=1)



As seen in the confusion matrix, the model mistakes the classes falcon and hawk. This is expected due to the visual similarities between these classes.

```
[45]: test_metrics = evaluate_model_performance(model, test_dataset, spark,
    ↪label_to_index)
```

```
2024-11-22 19:21:39.609012: I tensorflow/core/framework/local_rendezvous.cc:405]
Local rendezvous is aborting with status: OUT_OF_RANGE: End of sequence
```

```
68/68           1s 19ms/step
```

### Model Evaluation Report

---

Overall Metrics:  
 Accuracy: 0.9944  
 Weighted Precision: 0.9946  
 Weighted Recall: 0.9944  
 Weighted F1: 0.9944

Per-class Metrics:

---

Class	Precision	Recall	F1-Score	Support
antelope	1.0000	0.9688	0.9841	32
bear	1.0000	1.0000	1.0000	32
beaver	0.9706	1.0000	0.9851	33
bee	1.0000	1.0000	1.0000	33
bison	0.9697	1.0000	0.9846	32
blackbird	1.0000	0.9688	0.9841	32
buffalo	1.0000	0.9688	0.9841	32
butterfly	1.0000	1.0000	1.0000	32
camel	1.0000	1.0000	1.0000	32
cat	1.0000	1.0000	1.0000	65
cheetah	1.0000	1.0000	1.0000	32
chimpanzee	1.0000	1.0000	1.0000	32
chinchilla	1.0000	1.0000	1.0000	33
cow	1.0000	1.0000	1.0000	33
crab	1.0000	1.0000	1.0000	32
crocodile	1.0000	0.9697	0.9846	33
deer	0.9697	1.0000	0.9846	32
dog	1.0000	1.0000	1.0000	69
dolphin	1.0000	1.0000	1.0000	32
donkey	1.0000	1.0000	1.0000	32
duck	0.9697	1.0000	0.9846	32
eagle	0.9706	1.0000	0.9851	33
elephant	1.0000	1.0000	1.0000	43
falcon	0.9394	0.9688	0.9538	32
ferret	0.9429	1.0000	0.9706	33
flamingo	1.0000	1.0000	1.0000	32
fox	1.0000	1.0000	1.0000	33
frog	1.0000	1.0000	1.0000	47
giraffe	1.0000	1.0000	1.0000	33
goat	1.0000	1.0000	1.0000	33
goose	1.0000	0.9697	0.9846	33
gorilla	1.0000	1.0000	1.0000	32
grasshopper	1.0000	1.0000	1.0000	33
hawk	0.9375	0.9091	0.9231	33
hedgehog	1.0000	1.0000	1.0000	32
hippopotamus	1.0000	1.0000	1.0000	32
hyena	1.0000	1.0000	1.0000	32
iguana	0.9706	1.0000	0.9851	33
jaguar	1.0000	1.0000	1.0000	27
kangaroo	1.0000	1.0000	1.0000	32
koala	1.0000	1.0000	1.0000	33
lemur	1.0000	1.0000	1.0000	32
leopard	1.0000	1.0000	1.0000	32
lizard	1.0000	1.0000	1.0000	33
lynx	1.0000	1.0000	1.0000	33
mole	1.0000	0.9615	0.9804	26

mongoose	1.0000	1.0000	1.0000	32
ostrich	1.0000	1.0000	1.0000	33
otter	1.0000	1.0000	1.0000	32
owl	1.0000	1.0000	1.0000	32
panda	1.0000	1.0000	1.0000	33
peacock	1.0000	1.0000	1.0000	33
penguin	1.0000	1.0000	1.0000	32
porcupine	1.0000	0.9697	0.9846	33
raccoon	1.0000	0.9697	0.9846	33
seal	1.0000	1.0000	1.0000	32
sheep	1.0000	1.0000	1.0000	33
snail	1.0000	1.0000	1.0000	32
snake	1.0000	1.0000	1.0000	33
spider	1.0000	1.0000	1.0000	32
squid	1.0000	1.0000	1.0000	32
walrus	1.0000	1.0000	1.0000	32
whale	1.0000	1.0000	1.0000	32
wolf	1.0000	1.0000	1.0000	33

## 1.10 With Spark MLlib

[46]: classifier = SparkImageClassifier(spark)

[47]: train\_features = classifier.create\_features\_df(train\_df)

```
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```

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1/1          0s 31ms/step
1/1          0s 29ms/step
1/1          0s 26ms/step
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```

```
[48]: model = classifier.train_classifier(train_features)
```

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24/11/22 19:39:09 WARN TaskSetManager: Stage 19 contains a task of very large
size (11385 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:39:11 WARN TaskSetManager: Stage 22 contains a task of very large
size (11385 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:39:11 WARN TaskSetManager: Stage 23 contains a task of very large
size (11385 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:39:12 WARN TaskSetManager: Stage 24 contains a task of very large
size (11385 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:39:19 WARN TaskSetManager: Stage 26 contains a task of very large
size (11385 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:39:22 WARN TaskSetManager: Stage 28 contains a task of very large
size (11385 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:39:26 WARN DAGScheduler: Broadcasting large task binary with size
1147.0 KiB
24/11/22 19:39:26 WARN TaskSetManager: Stage 30 contains a task of very large
size (11385 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:39:31 WARN DAGScheduler: Broadcasting large task binary with size
1237.2 KiB
24/11/22 19:39:31 WARN TaskSetManager: Stage 32 contains a task of very large
size (11385 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:39:37 WARN DAGScheduler: Broadcasting large task binary with size
1364.4 KiB
24/11/22 19:39:37 WARN TaskSetManager: Stage 34 contains a task of very large
size (11385 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:39:40 WARN DAGScheduler: Broadcasting large task binary with size
1595.8 KiB
24/11/22 19:39:40 WARN TaskSetManager: Stage 36 contains a task of very large
size (11385 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:39:44 WARN DAGScheduler: Broadcasting large task binary with size
1918.9 KiB
24/11/22 19:39:44 WARN TaskSetManager: Stage 38 contains a task of very large
size (11385 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:39:48 WARN DAGScheduler: Broadcasting large task binary with size
2.2 MiB
24/11/22 19:39:48 WARN TaskSetManager: Stage 40 contains a task of very large
size (11385 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:39:52 WARN DAGScheduler: Broadcasting large task binary with size
```

2.5 MiB  
24/11/22 19:39:52 WARN TaskSetManager: Stage 42 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:39:55 WARN DAGScheduler: Broadcasting large task binary with size 2.9 MiB  
24/11/22 19:39:55 WARN TaskSetManager: Stage 44 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:39:58 WARN DAGScheduler: Broadcasting large task binary with size 2026.2 KiB  
24/11/22 19:39:58 WARN TaskSetManager: Stage 46 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:01 WARN DAGScheduler: Broadcasting large task binary with size 2.4 MiB  
24/11/22 19:40:01 WARN TaskSetManager: Stage 48 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:04 WARN DAGScheduler: Broadcasting large task binary with size 2.2 MiB  
24/11/22 19:40:04 WARN TaskSetManager: Stage 50 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:07 WARN DAGScheduler: Broadcasting large task binary with size 2.5 MiB  
24/11/22 19:40:07 WARN TaskSetManager: Stage 52 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:13 WARN DAGScheduler: Broadcasting large task binary with size 1868.8 KiB  
24/11/22 19:40:13 WARN TaskSetManager: Stage 54 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:16 WARN DAGScheduler: Broadcasting large task binary with size 1904.3 KiB  
24/11/22 19:40:16 WARN TaskSetManager: Stage 56 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:19 WARN DAGScheduler: Broadcasting large task binary with size 2.3 MiB  
24/11/22 19:40:19 WARN TaskSetManager: Stage 58 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:22 WARN DAGScheduler: Broadcasting large task binary with size 2.3 MiB  
24/11/22 19:40:22 WARN TaskSetManager: Stage 60 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:25 WARN DAGScheduler: Broadcasting large task binary with size 2.4 MiB  
24/11/22 19:40:25 WARN TaskSetManager: Stage 62 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:27 WARN DAGScheduler: Broadcasting large task binary with size 2.5 MiB  
24/11/22 19:40:28 WARN TaskSetManager: Stage 64 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:31 WARN DAGScheduler: Broadcasting large task binary with size

2.1 MiB  
24/11/22 19:40:31 WARN TaskSetManager: Stage 66 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:34 WARN DAGScheduler: Broadcasting large task binary with size 2.1 MiB  
24/11/22 19:40:34 WARN TaskSetManager: Stage 68 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:37 WARN DAGScheduler: Broadcasting large task binary with size 2.3 MiB  
24/11/22 19:40:37 WARN TaskSetManager: Stage 70 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:40 WARN DAGScheduler: Broadcasting large task binary with size 2.3 MiB  
24/11/22 19:40:40 WARN TaskSetManager: Stage 72 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:43 WARN DAGScheduler: Broadcasting large task binary with size 2.6 MiB  
24/11/22 19:40:43 WARN TaskSetManager: Stage 74 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:49 WARN DAGScheduler: Broadcasting large task binary with size 2.4 MiB  
24/11/22 19:40:49 WARN TaskSetManager: Stage 76 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:52 WARN DAGScheduler: Broadcasting large task binary with size 1739.6 KiB  
24/11/22 19:40:52 WARN TaskSetManager: Stage 78 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:54 WARN DAGScheduler: Broadcasting large task binary with size 2.1 MiB  
24/11/22 19:40:54 WARN TaskSetManager: Stage 80 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:40:57 WARN DAGScheduler: Broadcasting large task binary with size 1919.3 KiB  
24/11/22 19:40:57 WARN TaskSetManager: Stage 82 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:01 WARN DAGScheduler: Broadcasting large task binary with size 2.2 MiB  
24/11/22 19:41:01 WARN TaskSetManager: Stage 84 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:04 WARN DAGScheduler: Broadcasting large task binary with size 2.4 MiB  
24/11/22 19:41:04 WARN TaskSetManager: Stage 86 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:07 WARN DAGScheduler: Broadcasting large task binary with size 2.8 MiB  
24/11/22 19:41:07 WARN TaskSetManager: Stage 88 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:10 WARN DAGScheduler: Broadcasting large task binary with size

2.8 MiB  
24/11/22 19:41:10 WARN TaskSetManager: Stage 90 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:13 WARN DAGScheduler: Broadcasting large task binary with size 1852.9 KiB  
24/11/22 19:41:13 WARN TaskSetManager: Stage 92 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:16 WARN DAGScheduler: Broadcasting large task binary with size 1730.0 KiB  
24/11/22 19:41:17 WARN TaskSetManager: Stage 94 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:23 WARN DAGScheduler: Broadcasting large task binary with size 2.1 MiB  
24/11/22 19:41:23 WARN TaskSetManager: Stage 96 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:27 WARN DAGScheduler: Broadcasting large task binary with size 2.2 MiB  
24/11/22 19:41:27 WARN TaskSetManager: Stage 98 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:30 WARN DAGScheduler: Broadcasting large task binary with size 2.6 MiB  
24/11/22 19:41:30 WARN TaskSetManager: Stage 100 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:33 WARN DAGScheduler: Broadcasting large task binary with size 3.0 MiB  
24/11/22 19:41:33 WARN TaskSetManager: Stage 102 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:36 WARN DAGScheduler: Broadcasting large task binary with size 1582.5 KiB  
24/11/22 19:41:36 WARN TaskSetManager: Stage 104 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:39 WARN DAGScheduler: Broadcasting large task binary with size 1780.5 KiB  
24/11/22 19:41:39 WARN TaskSetManager: Stage 106 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:42 WARN DAGScheduler: Broadcasting large task binary with size 2.1 MiB  
24/11/22 19:41:42 WARN TaskSetManager: Stage 108 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:44 WARN DAGScheduler: Broadcasting large task binary with size 2.7 MiB  
24/11/22 19:41:44 WARN TaskSetManager: Stage 110 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:48 WARN DAGScheduler: Broadcasting large task binary with size 2.6 MiB  
24/11/22 19:41:48 WARN TaskSetManager: Stage 112 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:51 WARN DAGScheduler: Broadcasting large task binary with size

1929.9 KiB  
24/11/22 19:41:51 WARN TaskSetManager: Stage 114 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:54 WARN DAGScheduler: Broadcasting large task binary with size 1614.8 KiB  
24/11/22 19:41:54 WARN TaskSetManager: Stage 116 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:56 WARN DAGScheduler: Broadcasting large task binary with size 2.0 MiB  
24/11/22 19:41:56 WARN TaskSetManager: Stage 118 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:41:59 WARN DAGScheduler: Broadcasting large task binary with size 1792.5 KiB  
24/11/22 19:41:59 WARN TaskSetManager: Stage 120 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:42:01 WARN DAGScheduler: Broadcasting large task binary with size 1923.2 KiB  
24/11/22 19:42:01 WARN TaskSetManager: Stage 122 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:42:04 WARN DAGScheduler: Broadcasting large task binary with size 2.3 MiB  
24/11/22 19:42:04 WARN TaskSetManager: Stage 124 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.  
24/11/22 19:42:06 WARN DAGScheduler: Broadcasting large task binary with size 2.5 MiB  
24/11/22 19:42:06 WARN TaskSetManager: Stage 126 contains a task of very large size (11385 KiB). The maximum recommended task size is 1000 KiB.

[49]: metrics, predictions = classifier.evaluate\_classifier(model, test\_df)

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24/11/22 19:45:32 WARN DAGScheduler: Broadcasting large task binary with size
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24/11/22 19:45:32 WARN TaskSetManager: Stage 128 contains a task of very large
size (2436 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:45:33 WARN DAGScheduler: Broadcasting large task binary with size
18.9 MiB
24/11/22 19:45:33 WARN TaskSetManager: Stage 130 contains a task of very large
size (2436 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:45:34 WARN DAGScheduler: Broadcasting large task binary with size
18.9 MiB
24/11/22 19:45:34 WARN TaskSetManager: Stage 132 contains a task of very large
size (2436 KiB). The maximum recommended task size is 1000 KiB.
24/11/22 19:45:35 WARN DAGScheduler: Broadcasting large task binary with size
18.9 MiB
24/11/22 19:45:35 WARN TaskSetManager: Stage 134 contains a task of very large
size (2436 KiB). The maximum recommended task size is 1000 KiB.
```

```
[50]: print("=" * 50)
for metric, value in metrics.items():
```

```
print(f"{metric}: {value:.4f}")  
=====  
accuracy: 0.9866  
weightedPrecision: 0.9869  
weightedRecall: 0.9866  
f1: 0.9865
```

## 1.11 Model Comparison

### 1.11.1 TensorFlow Model

Overall metrics:

- Accuracy: 0.9944
- Weighted precision: 0.9946
- Weighted recall: 0.9944
- Weighted F1 score: 0.9944

### 1.11.2 Spark ML Model

Overall metrics:

- Accuracy: 0.9866
- Weighted precision: 0.9869
- Weighted recall: 0.9866
- Weighted F1 score: 0.9865

### 1.11.3 Comparison Analysis

- **Performance difference:** the first model slightly outperforms the second model across all metrics. Both models show extremely high performance overall, with >98% accuracy.
- **Consistency:** both models show very balanced metrics, meaning their precision and recall are nearly identical. There's no significant trade-off between precision and recall in either model.
- **Specific differences:** the first model has a higher precision, better recall, and better overall F1 score.

## 1.12 Conclusion

In conclusion, while both models demonstrate excellent performance with accuracy above 98%, the first model has a slight edge across all metrics. The difference, while measurable, is relatively small (about 1.1%), and both models would be considered highly successful for most practical applications. The consistency between precision and recall in both models suggests they're well-balanced and reliable classifiers.