

# Week\_10\_Data\_Centric\_AI

November 11, 2024

```
[17]: # Standard Libraries
import os
import io
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

# Image Processing
import cv2
from PIL import Image
from skimage.feature import graycomatrix, graycoprops
from skimage.metrics import structural_similarity as ssim

# File Handling
import h5py

# Deep Learning and PyTorch
import torch
import torch.nn as nn
import torch.nn.functional as F
import torch.optim as optim
from torch.utils.data import Dataset, DataLoader
from torchvision import models, transforms

# Metrics and Evaluation
from sklearn.metrics import classification_report, roc_auc_score, roc_curve, auc

# Progress Visualization
from tqdm import tqdm
```

## 0.1 Data improvements and enhancements

### 0.1.1 Feature Extraction

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[27]: # Feature extraction functions

def extract_color_histogram(image, bins=(8, 8, 8)):
    """Extracts a color histogram from an RGB image."""
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try:
    # Convert image from BGR to RGB color space
    image_rgb = cv2.cvtColor(image, cv2.COLOR_BGR2RGB)

    # Calculate the color histogram for the RGB image
    hist = cv2.calcHist([image_rgb], [0, 1, 2], None, bins, [0, 256, 0,
↪256, 0, 256])

    # Normalize and flatten the histogram to create a feature vector
    hist = cv2.normalize(hist, hist).flatten()
    return hist
except Exception as e:
    print(f"Error in extracting color histogram: {e}")
    return None

def extract_hu_moments(image):
    """Extracts Hu Moments from a grayscale image."""
    try:
        # Convert image to grayscale
        gray_image = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)

        # Compute image moments
        moments = cv2.moments(gray_image)

        # Calculate Hu Moments and flatten the array
        hu_moments = cv2.HuMoments(moments).flatten()
        return hu_moments
    except Exception as e:
        print(f"Error in extracting Hu moments: {e}")
        return None

def extract_haralick_texture(image):
    """Extracts Haralick texture features from a grayscale image."""
    try:
        # Convert image to grayscale
        gray_image = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)

        # Compute the gray-level co-occurrence matrix (GLCM)
        glcm = graycomatrix(gray_image, distances=[1], angles=[0], levels=256,
↪symmetric=True, normed=True)

        # Extract Haralick texture properties and flatten them into a feature
↪vector
        haralick_features = [graycoprops(glcm, prop).flatten()[0] for prop in
↪['contrast', 'dissimilarity', 'homogeneity', 'energy', 'correlation', 'ASM']]
        return np.array(haralick_features)
    except Exception as e:

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        print(f"Error in extracting Haralick texture: {e}")
        return None

def extract_image_features_from_hdf5(filename, convert_to_grayscale=True):
    """
    Extracts image features from an HDF5 file and pairs them with their
    ↪corresponding keys.

    Parameters:
    - filename (str): Path to the HDF5 file containing image data.
    - convert_to_grayscale (bool): Whether to convert images to grayscale
    ↪(default is True).

    Returns:
    - features_dict (dict): A dictionary where keys are image IDs and values
    ↪are feature vectors.
    """
    features_dict = {}

    try:
        # Open the HDF5 file
        with h5py.File(filename, "r") as f:
            # List all keys in the HDF5 file (image IDs)
            keys = list(f.keys())
            print("Keys: %s" % keys)

            # Iterate over each key to extract image data and features
            for key in keys:
                try:
                    # Read binary image data from the HDF5 file
                    binary_data = f[key][()]

                    # Convert the binary data to an image using PIL, then to a
                    ↪NumPy array for OpenCV
                    image = Image.open(io.BytesIO(binary_data))
                    image_bgr = cv2.cvtColor(np.array(image), cv2.COLOR_RGB2BGR)

                    # Check for NaN or infinite values in the image array
                    if np.isnan(image_bgr).any() or np.isinf(image_bgr).any():
                        print(f"Warning: Image from key '{key}' contains NaN or
                        ↪infinite values.")
                        continue

                    # Extract various features from the image
                    color_hist = extract_color_histogram(image_bgr)
                    hu_moments = extract_hu_moments(image_bgr)
                    haralick_texture = extract_haralick_texture(image_bgr)

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        # Ensure all extracted features are valid before combining
        if color_hist is None or hu_moments is None or
↳haralick_texture is None:
            print(f"Warning: One or more feature extractions failed,
↳for key '{key}'. Skipping.")
            continue

        # Combine all features into a single global feature vector
        global_feature = np.hstack([color_hist, hu_moments,
↳haralick_texture])

        # Store the feature vector in the dictionary, paired with
↳the key
        features_dict[key] = global_feature

    except Exception as e:
        print(f"Error processing key '{key}': {e}")
        continue

    except IOError as e:
        print(f"Error opening HDF5 file: {e}")
    except Exception as e:
        print(f"Unexpected error: {e}")

    print(f"Extracted features from {len(features_dict)} images.")
    return features_dict

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### 0.1.2 Principle Component Analysis

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[28]: def perform_pca_on_image_dataset(train_filename, val_filename=None,
↳resize_shape=(128, 128), num_images_to_display=5):
    """
    Performs PCA on a training image dataset and optionally applies PCA to a
↳validation dataset, pairing results with keys.

    Parameters:
    - train_filename (str): Path to the training HDF5 file.
    - val_filename (str, optional): Path to the validation HDF5 file (default
↳is None).
    - resize_shape (tuple): The size to which images will be resized (default
↳is (128, 128)).
    - num_images_to_display (int): Number of images to display for visual
↳comparison (default is 5).

    Returns:

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- tuple: Dictionaries containing PCA results and reconstructed images for
↳ training and optionally validation.
"""
def load_image_dataset(filename):
    """Loads and preprocesses images from an HDF5 file and pairs them with
↳ keys."""
    image_dataset = {} # Dictionary to store image data with keys
    try:
        with h5py.File(filename, "r") as f:
            # Get all keys (image IDs) in the HDF5 file
            keys = list(f.keys())
            print("Keys found:", keys)

            for key in keys:
                # Load binary image data from the HDF5 file
                binary_data = f[key][()]
                # Convert binary data to a PIL image and then to grayscale
                image = Image.open(io.BytesIO(binary_data)).convert('L')
                # Resize the image to a consistent shape
                image = image.resize(resize_shape)
                # Flatten the image and convert to a NumPy array
                image_array = np.array(image).astype(float).flatten()

                # Check for NaN or infinite values and skip invalid images
                if np.isnan(image_array).any() or np.isinf(image_array).
↳ any():
                    print(f"Warning: Image from key '{key}' contains NaN or
↳ infinite values.")
                    continue

                # Store the processed image in the dictionary
                image_dataset[key] = image_array
    except Exception as e:
        print(f"Error loading HDF5 file {filename}: {e}")
        raise

    return image_dataset

# Load and process the training dataset
train_dataset = load_image_dataset(train_filename)
if not train_dataset:
    raise ValueError("No valid images found in the training dataset.")

print(f"Training dataset contains {len(train_dataset)} images.")

pca_result_val, reconstructed_val = None, None

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try:
    # Extract image keys and convert the dataset to a NumPy array for PCA
    train_keys = list(train_dataset.keys())
    train_images = np.array(list(train_dataset.values()))

    # Apply PCA to the training dataset, retaining 95% of the variance
    pca = PCA(n_components=0.95)
    pca_result_train = pca.fit_transform(train_images)
    reconstructed_train = pca.inverse_transform(pca_result_train)

    # Pair PCA results and reconstructed images with their corresponding
    ↪keys
    reconstructed_train_dict = {key: reconstructed for key, reconstructed
    ↪in zip(train_keys, reconstructed_train)}
    pca_result_train_dict = {key: pca_result for key, pca_result in
    ↪zip(train_keys, pca_result_train)}

    # Display a few training images and their PCA-reconstructed versions
    for i, (key, original, reconstructed) in enumerate(zip(train_keys,
    ↪train_images, reconstructed_train)):
        if i >= num_images_to_display:
            break

        # Reshape the original and reconstructed images for display
        original_image = original.reshape(resize_shape)
        reconstructed_image = reconstructed.reshape(resize_shape)

        # Plot original and reconstructed images side by side
        fig, axes = plt.subplots(1, 2, figsize=(10, 5))
        axes[0].imshow(original_image, cmap='gray')
        axes[0].set_title('Original Image')
        axes[0].axis('off')

        axes[1].imshow(reconstructed_image, cmap='gray')
        axes[1].set_title('PCA Transformed Image')
        axes[1].axis('off')

        plt.suptitle(f"Training Image {key}")
        plt.show()

    # Calculate and display mean squared error (MSE) and structural
    ↪similarity index (SSIM)
    mse = np.mean((original_image - reconstructed_image) ** 2)
    similarity_index = ssim(original_image, reconstructed_image,
    ↪data_range=original_image.max() - original_image.min())

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        print(f"Mean Squared Error (MSE) for training image {key}: {mse:.4f}")

        print(f"Structural Similarity Index (SSIM) for training image {key}: {similarity_index:.4f}")

        # Process the validation dataset if provided
        if val_filename:
            val_dataset = load_image_dataset(val_filename)
            if not val_dataset:
                print("Warning: No valid images found in the validation dataset.")
            else:
                print(f"Validation dataset contains {len(val_dataset)} images.")

                val_keys = list(val_dataset.keys())
                val_images = np.array(list(val_dataset.values()))

                # Apply the trained PCA to the validation dataset
                pca_result_val = pca.transform(val_images)
                reconstructed_val = pca.inverse_transform(pca_result_val)

                # Pair PCA results and reconstructed images with their
                # corresponding keys
                reconstructed_val_dict = {key: reconstructed for key,
                reconstructed in zip(val_keys, reconstructed_val)}
                pca_result_val_dict = {key: pca_result for key, pca_result in
                zip(val_keys, pca_result_val)}

                # Display a few validation images and their PCA-reconstructed
                # versions
                for i, (key, original, reconstructed) in
                enumerate(zip(val_keys, val_images, reconstructed_val)):
                    if i >= num_images_to_display:
                        break

                    original_image = original.reshape(resize_shape)
                    reconstructed_image = reconstructed.reshape(resize_shape)

                    fig, axes = plt.subplots(1, 2, figsize=(10, 5))
                    axes[0].imshow(original_image, cmap='gray')
                    axes[0].set_title('Original Validation Image')
                    axes[0].axis('off')

                    axes[1].imshow(reconstructed_image, cmap='gray')
                    axes[1].set_title('PCA Transformed Validation Image')
                    axes[1].axis('off')

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plt.suptitle(f"Validation Image {key}")
plt.show()

mse = np.mean((original_image - reconstructed_image) ** 2)
similarity_index = ssim(original_image,
↪reconstructed_image, data_range=original_image.max() - original_image.min())

print(f"Mean Squared Error (MSE) for validation image {key}:
↪ {mse:.4f}")

print(f"Structural Similarity Index (SSIM) for validation
↪image {key}: {similarity_index:.4f}")

except Exception as e:
    print(f"Error performing PCA: {e}")
    raise

return reconstructed_train_dict, pca_result_train_dict,
↪(reconstructed_val_dict, pca_result_val_dict) if val_filename else (None,
↪None)

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## Combine Extracted Features and PCA Features to the Data Frame

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[29]: # File paths for the training, validation, and test HDF5 image data
train_filename = "../data/raw/train_images.hdf5"
val_filename = "../data/raw/validation_image.hdf5"
test_filename = "../data/raw/test_image.hdf5"

# Perform PCA on the training and validation datasets, obtaining the PCA
↪features
_, pca_features_train, (_, pca_features_val) =
↪perform_pca_on_image_dataset(train_filename, val_filename)

# Perform PCA on the training and test datasets, obtaining the PCA features for
↪testing
_, _, (_, pca_features_test) = perform_pca_on_image_dataset(train_filename,
↪test_filename)

# Extract image features (e.g., color histograms, Hu moments, Haralick
↪textures) from the training dataset
train_image_features = extract_image_features_from_hdf5(train_filename)

# Extract image features from the validation dataset
val_image_features = extract_image_features_from_hdf5(val_filename)

# Extract image features from the test dataset
test_image_features = extract_image_features_from_hdf5(test_filename)

```



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# Load metadata CSV files for training, validation, and test data
train_df = pd.read_csv('../data/processed/processed-train-metadata1.csv')
val_df = pd.read_csv('../data/processed/processed-validation-metadata1.csv')
test_df = pd.read_csv('../data/processed/processed-test-metadata1.csv')

# Ensure that the 'isic_id' column in the dataframes is of type string to match
↳ the keys in the extracted features
train_df['isic_id'] = train_df['isic_id'].astype(str)
val_df['isic_id'] = val_df['isic_id'].astype(str)
test_df['isic_id'] = test_df['isic_id'].astype(str)

# Add a new column to the training DataFrame with extracted features by mapping
↳ 'isic_id' to the corresponding feature vector
train_df['extracted_features'] = train_df['isic_id'].apply(lambda x:
↳ train_image_features.get(x, None))

# Add a new column to the validation DataFrame with extracted features
val_df['extracted_features'] = val_df['isic_id'].apply(lambda x:
↳ val_image_features.get(x, None))

# Add a new column to the test DataFrame with extracted features
test_df['extracted_features'] = test_df['isic_id'].apply(lambda x:
↳ test_image_features.get(x, None))

# Add a new column to the training DataFrame with PCA features by mapping
↳ 'isic_id' to the corresponding PCA feature vector
train_df['pca_features'] = train_df['isic_id'].apply(lambda x:
↳ pca_features_train.get(x, None))

# Add a new column to the validation DataFrame with PCA features
val_df['pca_features'] = val_df['isic_id'].apply(lambda x: pca_features_val.
↳ get(x, None))

# Add a new column to the test DataFrame with PCA features
test_df['pca_features'] = test_df['isic_id'].apply(lambda x: pca_features_test.
↳ get(x, None))

```

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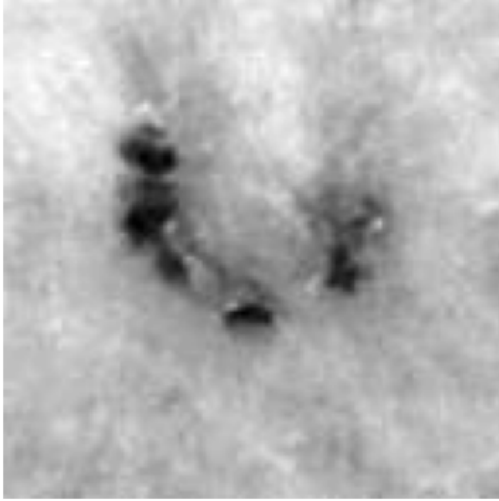
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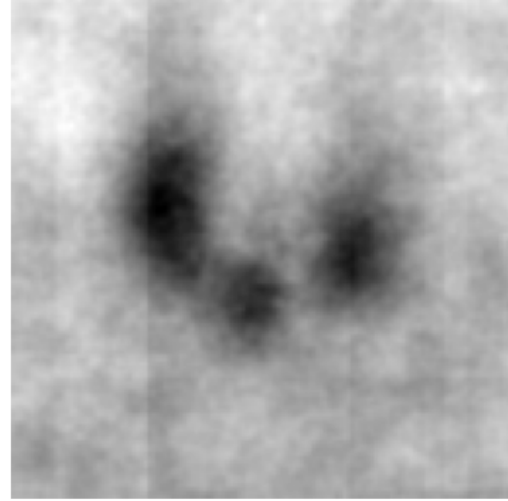


Training Image ISIC\_0082829

Original Image



PCA Transformed Image

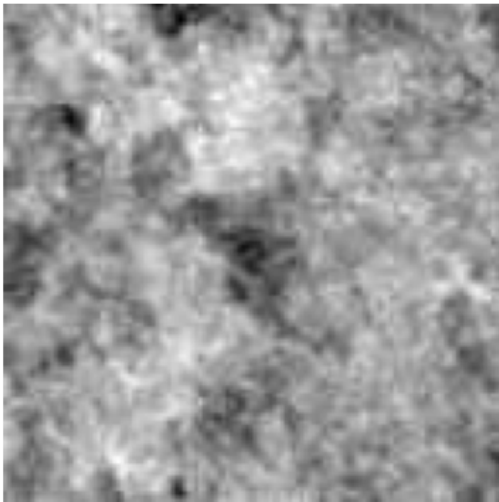


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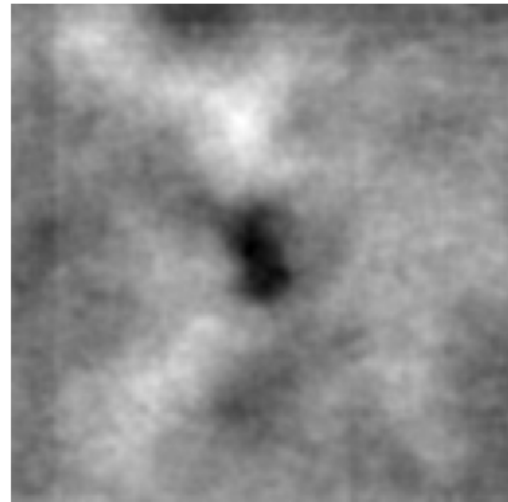
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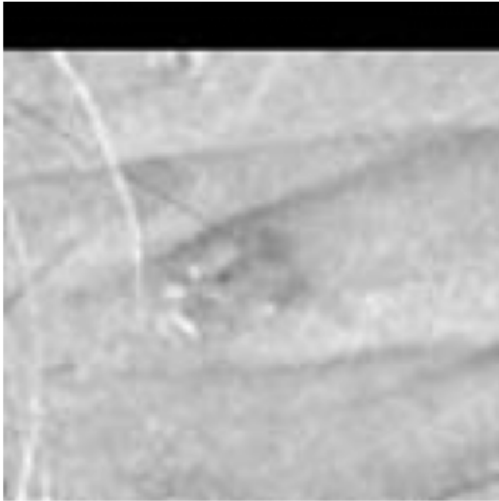


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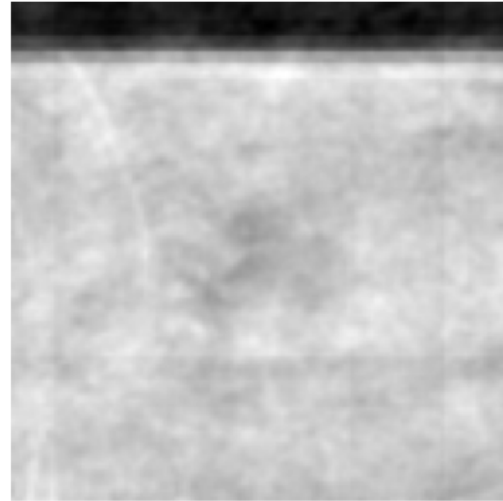
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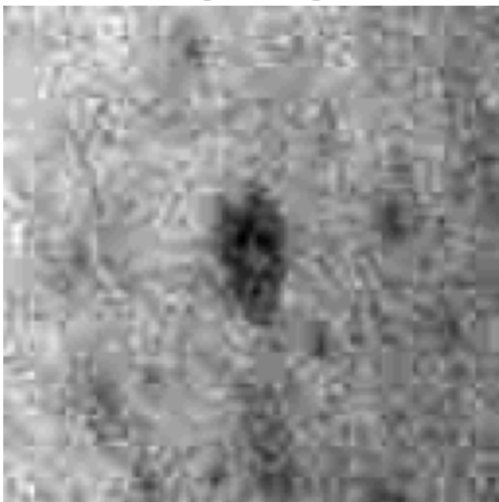


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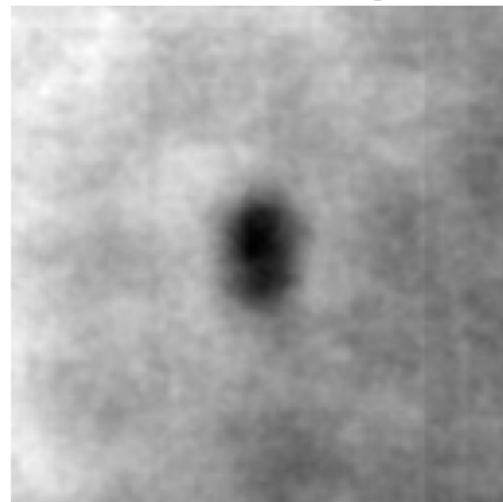
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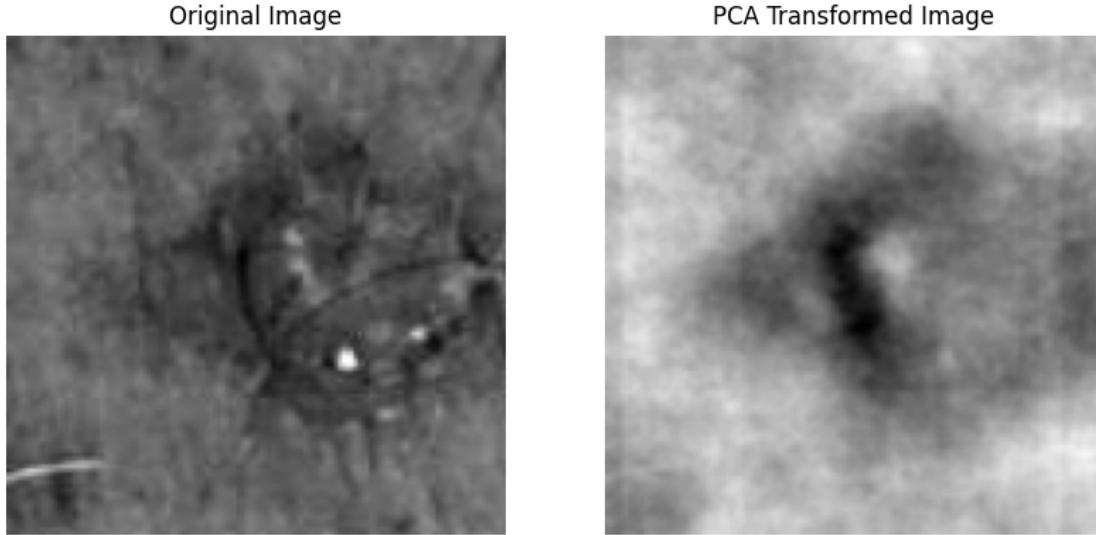
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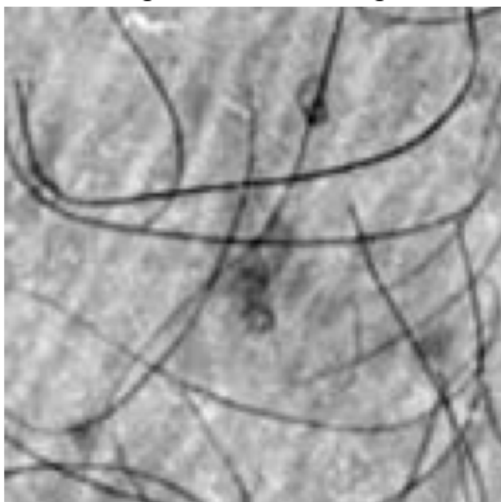


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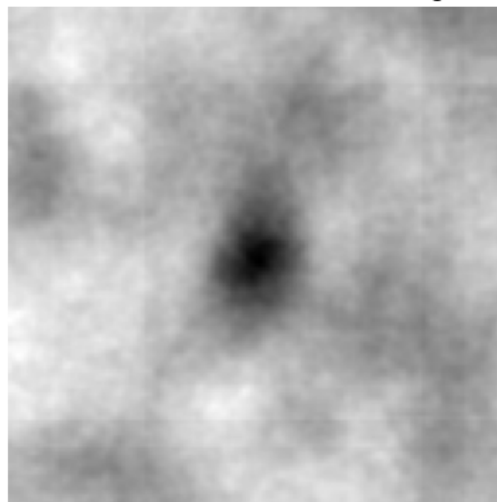
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Validation Image ISIC\_0086819

Original Validation Image



PCA Transformed Validation Image

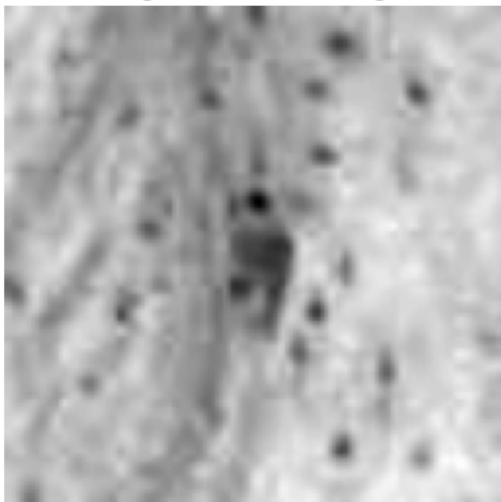


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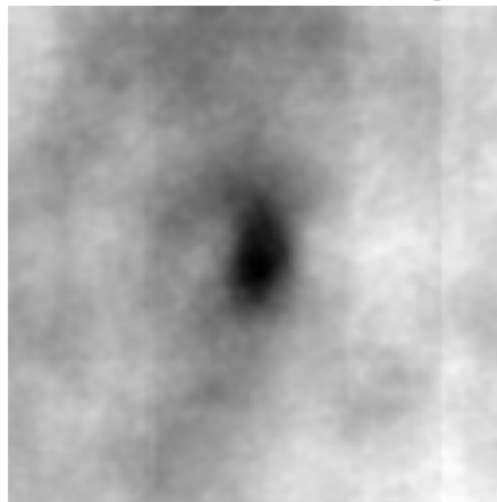
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Original Validation Image



PCA Transformed Validation Image



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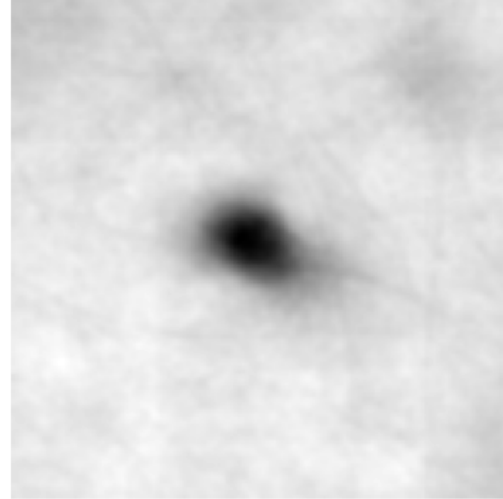
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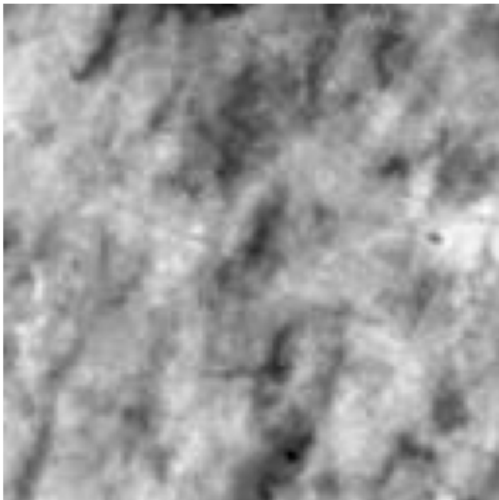


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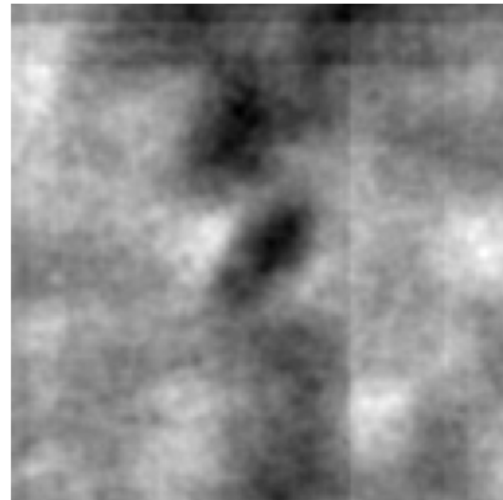
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PCA Transformed Validation Image



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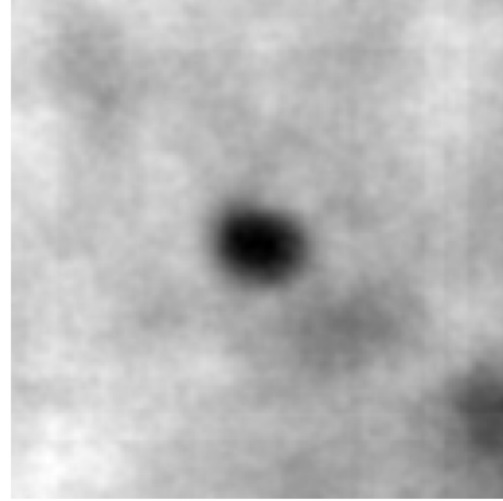
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### Validation Image ISIC\_0108610

Original Validation Image



PCA Transformed Validation Image



Mean Squared Error (MSE) for validation image ISIC\_0108610: 29.1011

Structural Similarity Index (SSIM) for validation image ISIC\_0108610: 0.4591

Shape of PCA-reconstructed training image array: (1649, 16384)

Shape of PCA-reconstructed validation image array: (1490, 16384)

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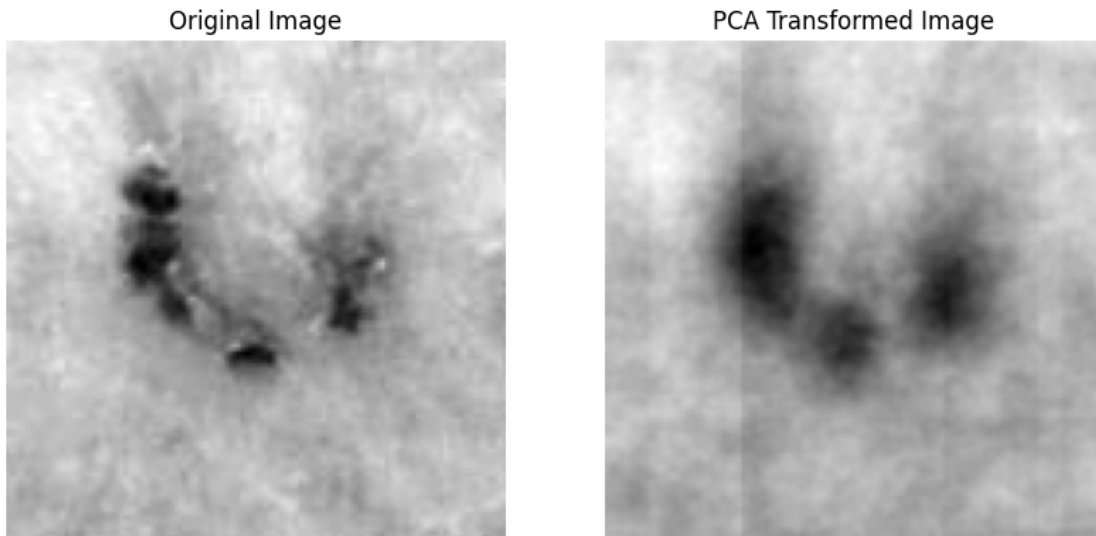
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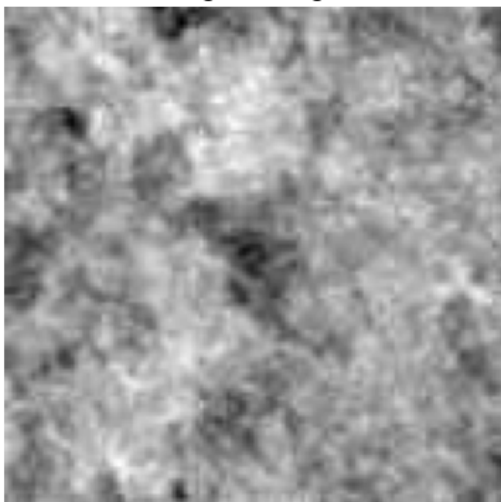


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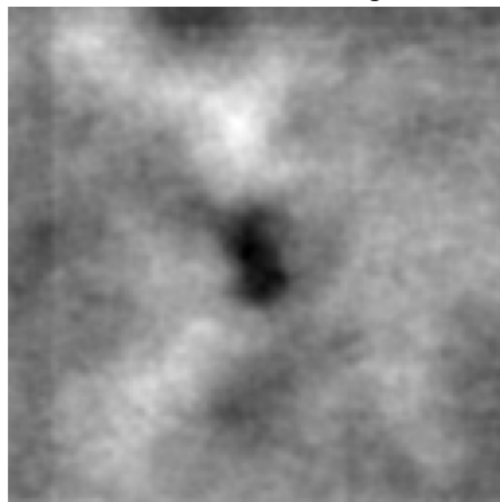
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Training Image ISIC\_0084964

Original Image



PCA Transformed Image

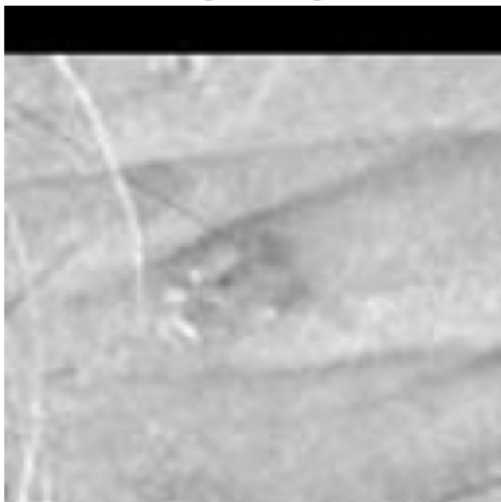


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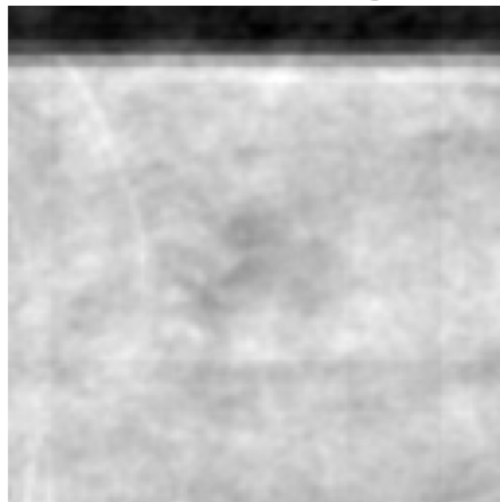
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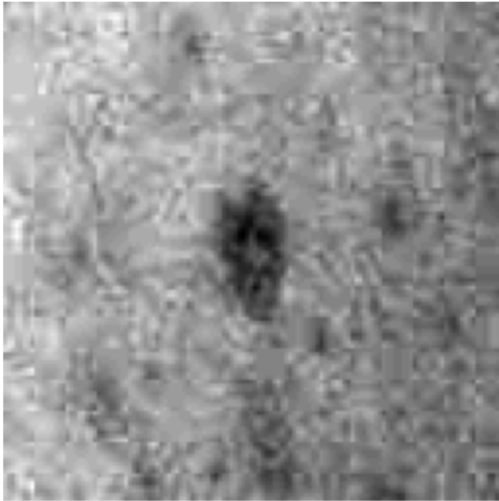


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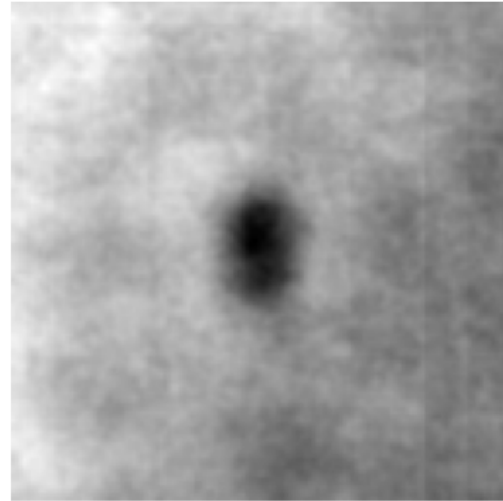
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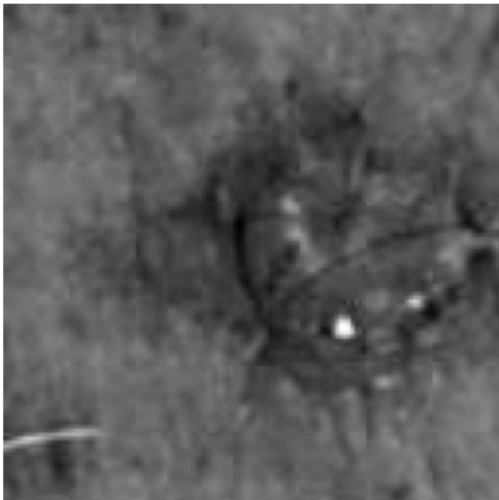


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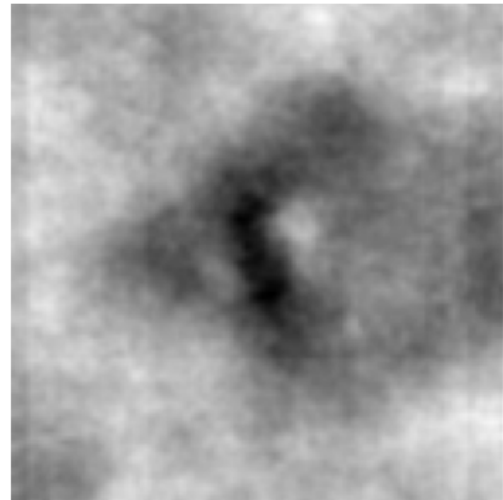
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Training Image ISIC\_0104229

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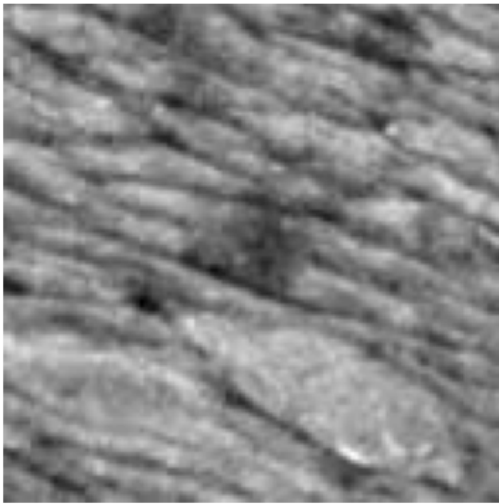
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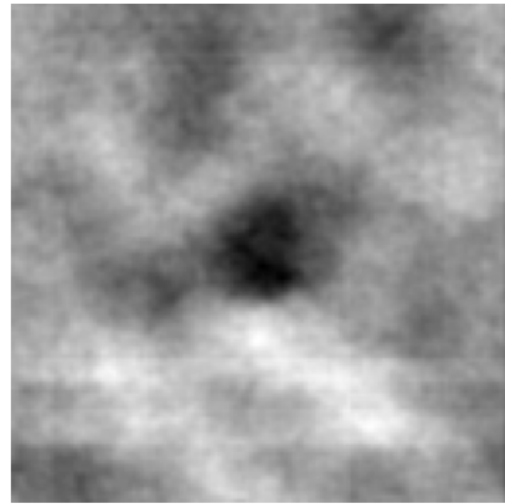
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Original Validation Image



PCA Transformed Validation Image

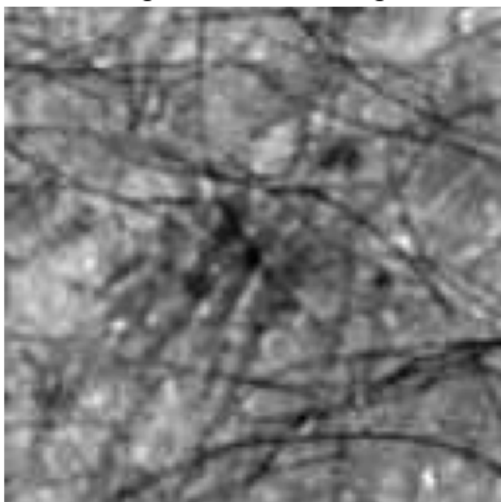


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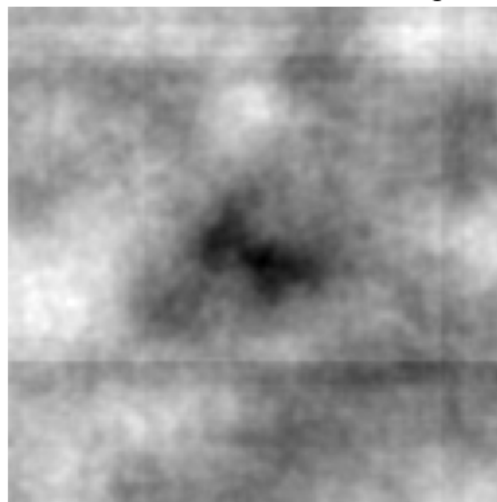
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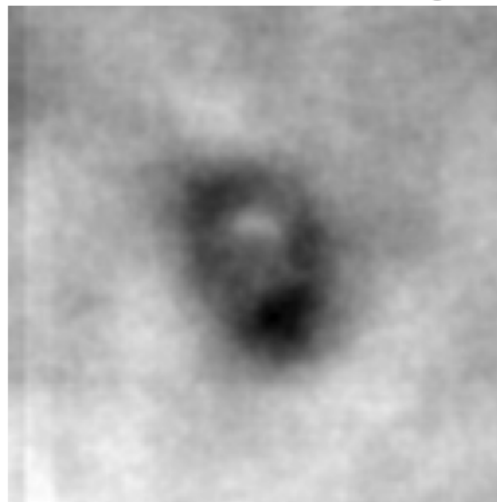
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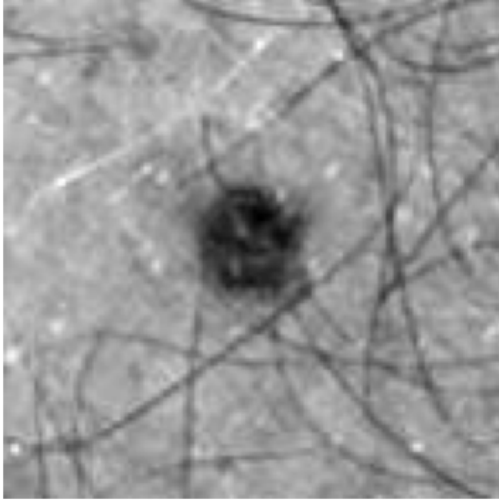


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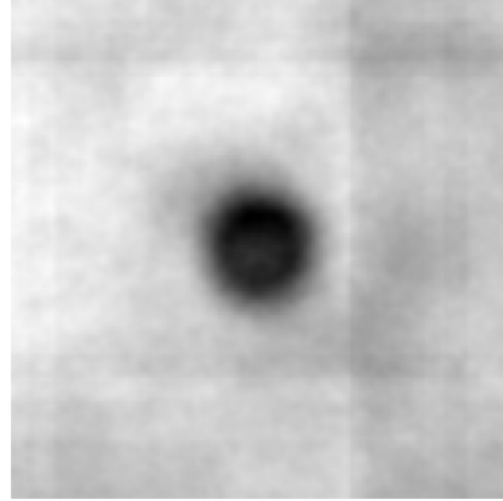
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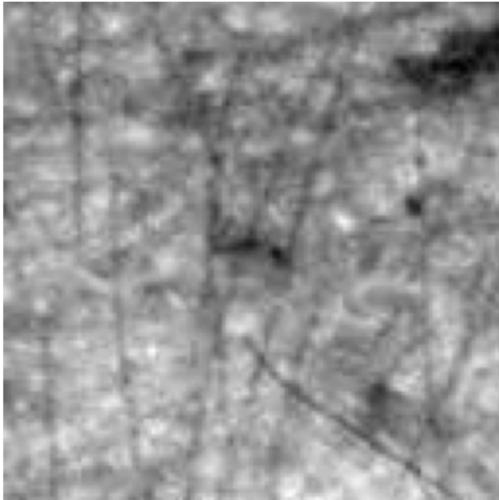
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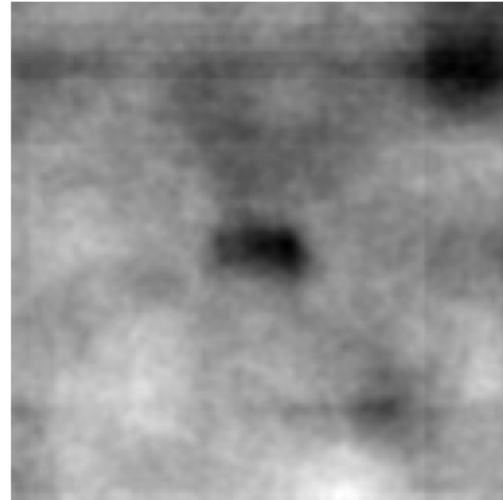
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Validation Image ISIC\_0086083

Original Validation Image



PCA Transformed Validation Image



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```

Extracted features from 1490 images.

### 0.1.3 Image Data Augmentation

```
[30]: def get_train_transform(resize_size=(256, 256), crop_size=224,
    ↪rotation_degree=15, normalize_means=(0.485, 0.456, 0.406), normalize_stds=(0.
    ↪229, 0.224, 0.225)):
    """
    Returns the transformations for the training dataset, including data
    ↪augmentation for EfficientNet.

    Args:
        resize_size (tuple): The size to resize the image before cropping.
        crop_size (int): The size of the random crop.
        rotation_degree (int): Maximum degree for random rotation.
        normalize_means (tuple): Means for normalization (default matches
    ↪EfficientNet's training).
        normalize_stds (tuple): Standard deviations for normalization (default
    ↪matches EfficientNet's training).

    Returns:
        transforms.Compose: The composed transformations for the training set.
    """
    return transforms.Compose([
        transforms.Resize(resize_size), # Resize to a specified size
        transforms.RandomResizedCrop(crop_size, scale=(0.8, 1.0)), # Randomly
    ↪crop the resized image
        transforms.RandomHorizontalFlip(), # Random horizontal flipping for
    ↪augmentation
```

```

        transforms.RandomRotation(rotation_degree), # Random rotation
        transforms.ColorJitter(brightness=0.4, contrast=0.4, saturation=0.4,
        ↪hue=0.1), # Optional: Add color jitter for more augmentation
        transforms.ToTensor(), # Convert image to PyTorch tensor
        transforms.Normalize(normalize_means, normalize_std) # Normalize
        ↪using EfficientNet's means and stds
    ])

def get_normal_transform(resize_size=(256, 256), normalize_means=(0.485, 0.456,
        ↪0.406), normalize_std=(0.229, 0.224, 0.225)):
    """
    Returns the transformations for the validation/test dataset without data
    ↪augmentation, tailored for EfficientNet.

    Args:
        resize_size (tuple): The size to resize the image.
        normalize_means (tuple): Means for normalization (default matches
        ↪EfficientNet's training).
        normalize_std (tuple): Standard deviations for normalization (default
        ↪matches EfficientNet's training).

    Returns:
        transforms.Compose: The composed transformations for the validation/
        ↪test set.
    """
    return transforms.Compose([
        transforms.Resize(resize_size), # Resize to the specified size to
        ↪maintain consistency
        transforms.CenterCrop(224), # Center crop to match EfficientNet's
        ↪input size (224x224)
        transforms.ToTensor(), # Convert image to PyTorch tensor
        transforms.Normalize(normalize_means, normalize_std) # Normalize
        ↪using EfficientNet's means and stds
    ])

```

## 0.2 Dataset and Dataloader

```

[31]: class MultiInputDataset(Dataset):
        def __init__(self, hdf5_file, df, transform=None):
            """
            Multi-input dataset that includes images, extracted features, PCA
            ↪results, metadata, and labels.

            Parameters:
            - hdf5_file (str): Path to the HDF5 file containing image data.

```

```

        - df (pd.DataFrame): DataFrame containing image IDs, labels, and
        ↪ additional features.
        - transform (callable, optional): A function/transform to apply to the
        ↪ images.
    """
    # Open the HDF5 file
    try:
        self.hdf5_file = h5py.File(hdf5_file, 'r')
    except Exception as e:
        raise IOError(f"Could not open HDF5 file: {hdf5_file}. Error: {e}")

    # Store the DataFrame
    self.df = df
    self.image_ids = df['isic_id'].values

    # Check that all image IDs are in the HDF5 file
    for image_id in self.image_ids:
        if str(image_id) not in self.hdf5_file.keys():
            raise ValueError(f"Image id {image_id} not found in HDF5 file.")

    self.transform = transform

    def __len__(self):
        return len(self.df)

    def __getitem__(self, idx):
        # Get the image ID and load the image from HDF5
        image_id = str(self.df.iloc[idx]['isic_id'])
        image_bytes = self.hdf5_file[image_id][()]
        image = Image.open(io.BytesIO(image_bytes)).convert('RGB')

        # Apply any transformations
        if self.transform:
            image_transformed = self.transform(image)
        else:
            image_transformed = np.array(image)

        # Extract the features and PCA result directly from the DataFrame
        extracted_features = self.df.iloc[idx]['extracted_features']
        pca_features = self.df.iloc[idx]['pca_features']

        # Convert features to tensors
        extracted_features_tensor = torch.tensor(extracted_features,
        ↪ dtype=torch.float32)
        pca_features_tensor = torch.tensor(pca_features, dtype=torch.float32)

        # Retrieve the label

```

```

        label = torch.tensor(self.df.iloc[idx]['target'], dtype=torch.long)

        # Retrieve other metadata features (if any)
        other_variables = self.df.iloc[idx].drop(['isic_id', 'target',
        ↪ 'extracted_features', 'pca_features']).values.astype(float)
        metadata_tensor = torch.tensor(other_variables, dtype=torch.float32)

        # Return the image, extracted features, PCA features, metadata, and
        ↪ label
        return image_transformed, extracted_features_tensor,
        ↪ pca_features_tensor, metadata_tensor, label

```

```

[32]: train_dataset = MultiInputDataset('../data/raw/train_images.
        ↪ hdf5', train_df, transform=get_train_transform())
        val_dataset = MultiInputDataset('../data/raw/validation_image.
        ↪ hdf5', val_df, transform=get_normal_transform())
        test_dataset = MultiInputDataset('../data/raw/test_image.
        ↪ hdf5', test_df, transform=get_normal_transform())

```

```

[33]: # Create DataLoader objects for training, validation, and testing
        effnet_train_dataloader = DataLoader(train_dataset, batch_size=16, shuffle=True)
        effnet_val_dataloader = DataLoader(val_dataset, batch_size=16, shuffle=False)
        ↪ # Usually, we don't shuffle validation data
        effnet_test_dataloader = DataLoader(test_dataset, batch_size=16, shuffle=False)
        ↪ # Typically, test data is not shuffled

```

### 0.3 Model Architecture

```

[34]: # EfficientNet Model with extended input processing
class CustomImageFeatureEfficientNet(nn.Module):
    def __init__(self, extracted_feature_size, pca_feature_size, metadata_size,
    ↪ pretrained=True):
        """
        Initializes the CustomImageFeatureEfficientNet model with EfficientNet
        ↪ for image features and
        additional layers for extracted, PCA, and metadata inputs.

        Args:
            extracted_feature_size (int): The size of the extracted features
            ↪ input.
            pca_feature_size (int): The size of the PCA-transformed features
            ↪ input.
            metadata_size (int): The size of the metadata input.
            pretrained (bool): Whether to use a pretrained EfficientNet model.
        """
        super(CustomImageFeatureEfficientNet, self).__init__()

```

```

        # Load a pretrained EfficientNet model and remove the final
        ↪classification layer
        try:
            efficientnet = models.efficientnet_b0(pretrained=pretrained)
            self.efficientnet = nn.Sequential(*list(efficientnet.children())[:
        ↪-1])

            print("EfficientNet loaded successfully.")
        except Exception as e:
            print(f"Error loading EfficientNet model: {e}")
            raise

    # Fully connected layers for image features
    self.fc_image = nn.Sequential(
        nn.Linear(1280, 1024),
        nn.ReLU(),
        nn.BatchNorm1d(1024),
        nn.Dropout(0.8),
        nn.Linear(1024, 512),
        nn.ReLU(),
        nn.BatchNorm1d(512)
    )

    # Fully connected layers for extracted features
    self.fc_extracted_features = nn.Sequential(
        nn.Linear(extracted_feature_size, 512),
        nn.ReLU(),
        nn.BatchNorm1d(512),
        nn.Dropout(0.8),
        nn.Linear(512, 256),
        nn.ReLU(),
        nn.BatchNorm1d(256)
    )

    # Fully connected layers for PCA features
    self.fc_pca_features = nn.Sequential(
        nn.Linear(pca_feature_size, 256),
        nn.ReLU(),
        nn.BatchNorm1d(256),
        nn.Dropout(0.8),
        nn.Linear(256, 128),
        nn.ReLU(),
        nn.BatchNorm1d(128)
    )

    # Fully connected layers for metadata
    self.fc_metadata = nn.Sequential(

```

```

        nn.Linear(metadata_size, 128),
        nn.ReLU(),
        nn.BatchNorm1d(128),
        nn.Dropout(0.8),
        nn.Linear(128, 64),
        nn.ReLU(),
        nn.BatchNorm1d(64)
    )

    # Final classification layer for the combined features
    self.fc_combined = nn.Sequential(
        nn.Linear(512 + 256 + 128 + 64, 256), # Combined feature input size
        nn.ReLU(),
        nn.BatchNorm1d(256),
        nn.Dropout(0.8),
        nn.Linear(256, 64),
        nn.ReLU(),
        nn.Linear(64, 1) # Binary classification output
    )

def forward(self, image, extracted_features, pca_features, metadata):
    """
    Forward pass for the model, processing each input type and combining
    ↪ them.

    Args:
        image (torch.Tensor): The input image tensor.
        extracted_features (torch.Tensor): The extracted features tensor.
        pca_features (torch.Tensor): The PCA-transformed features tensor.
        metadata (torch.Tensor): The metadata tensor.

    Returns:
        torch.Tensor: The output prediction of the model.
    """
    try:
        # Pass the image through EfficientNet and process its output
        x = self.efficientnet(image)
        x = x.view(x.size(0), -1) # Flatten the output
        image_features = self.fc_image(x)

        # Process extracted features
        extracted_features_processed = self.
    ↪ fc_extracted_features(extracted_features)

        # Process PCA features
        pca_features_processed = self.fc_pca_features(pca_features)

```

```

        # Process metadata features
        metadata_features_processed = self.fc_metadata(metadata)

        # Concatenate all processed features
        combined_features = torch.cat((image_features,
        ↪extracted_features_processed, pca_features_processed,
        ↪metadata_features_processed), dim=1)

        # Final classification
        output = self.fc_combined(combined_features)

        # Apply sigmoid for binary classification (optional, depending on
        ↪loss function)
        output = torch.sigmoid(output)

        return output

    except Exception as e:
        print(f"Error during forward pass: {e}")
        raise

```

```

[35]: # Function to compute partial AUC-above-TPR
def score(solution: np.array, submission: np.array, min_tpr: float = 0.80) ->
    ↪float:
    """
        Compute the partial AUC by focusing on a specific range of true positive
        ↪rates (TPR).

        Args:
            solution (np.array): Ground truth binary labels.
            submission (np.array): Model predictions.
            min_tpr (float): Minimum true positive rate to calculate partial AUC.

        Returns:
            float: The calculated partial AUC.

        Raises:
            ValueError: If the min_tpr is not within a valid range.
    """
    # Rescale the target to handle sklearn limitations and flip the predictions
    v_gt = abs(solution - 1)
    v_pred = -1.0 * submission
    max_fpr = abs(1 - min_tpr)

    # Compute ROC curve using sklearn
    fpr, tpr, _ = roc_curve(v_gt, v_pred)
    if max_fpr is None or max_fpr == 1:

```



```

    return auc(fpr, tpr)
if max_fpr <= 0 or max_fpr > 1:
    raise ValueError(f"Expected min_tpr in range [0, 1), got: {min_tpr}")

# Interpolate for partial AUC
stop = np.searchsorted(fpr, max_fpr, "right")
x_interp = [fpr[stop - 1], fpr[stop]]
y_interp = [tpr[stop - 1], tpr[stop]]
tpr = np.append(tpr[:stop], np.interp(max_fpr, x_interp, y_interp))
fpr = np.append(fpr[:stop], max_fpr)
partial_auc = auc(fpr, tpr)

return partial_auc

# Training and validation loop function
def train_and_validate(
    model: nn.Module,
    train_dataloader: torch.utils.data.DataLoader,
    val_dataloader: torch.utils.data.DataLoader,
    criterion: nn.Module,
    optimizer: torch.optim.Optimizer,
    epochs: int,
    device: torch.device,
    best_model_path: str,
    early_stopping_patience: int = 5,
    min_tpr: float = 0.80
) -> nn.Module:
    """
    Train and validate a PyTorch model with early stopping, AUROC, partial AUC,
    and error handling.

    Args:
        model (nn.Module): The model to be trained and validated.
        train_dataloader (torch.utils.data.DataLoader): Dataloader for training
        data.
        val_dataloader (torch.utils.data.DataLoader): Dataloader for validation
        data.
        criterion (nn.Module): Loss function.
        optimizer (torch.optim.Optimizer): Optimizer to update the model.
        epochs (int): Number of training epochs.
        device (torch.device): The device (CPU or GPU) to use.
        early_stopping_patience (int): Early stopping patience.
        min_tpr (float): The minimum true positive rate for calculating partial
        AUC.

    Returns:

```

```

        nn.Module: The trained model.
        """
        # Initialize tracking variables
        best_val_loss = float('inf')
        best_epoch = 0
        train_losses = []
        val_losses = []
        train_accuracies = []
        val_accuracies = []
        early_stopping_counter = 0

        # Start the training and validation loop
        for epoch in range(epochs):
            print(f'Epoch {epoch + 1}/{epochs}')

            # Training phase
            model.train()
            running_train_loss = 0.0
            correct_train = 0
            total_train = 0
            all_train_labels = []
            all_train_probs = []

            progress_bar = tqdm(train_dataloader, desc=f'Training Epoch {epoch + 1}')

            try:
                # Loop through the training batches
                for i, (image, extracted_features, pca_feature, metadata, labels) in enumerate(progress_bar):
                    image, extracted_features, pca_feature, metadata, labels =
                    image.to(device), extracted_features.to(device), pca_feature.to(device),
                    metadata.to(device), labels.float().to(device)
                    labels = labels.unsqueeze(1) # Adjust labels to have the right
                    shape for binary classification

                    optimizer.zero_grad()

                    # Forward pass
                    probs = model(image, extracted_features, pca_feature, metadata)

                    if probs.shape != labels.shape:
                        raise ValueError(f"Shape mismatch: Predictions shape {probs.
                        shape} does not match labels shape {labels.shape}")

                    # Calculate loss and backpropagate
                    loss = criterion(probs, labels)

```

```

        loss.backward()
        optimizer.step()

        # Update running loss
        running_train_loss += loss.item()

        # Store labels and predictions for accuracy calculations
        all_train_labels.extend(labels.cpu().detach().numpy())
        all_train_probs.extend(probs.cpu().detach().numpy())

        # Calculate binary predictions for training accuracy
        predicted_train = (probs >= 0.5).float()
        total_train += labels.size(0)
        correct_train += (predicted_train == labels).sum().item()

        # Update progress bar
        progress_bar.set_postfix(train_loss=running_train_loss / (i + 1))

    # Calculate training accuracy and loss
    train_accuracy = 100 * correct_train / total_train
    train_losses.append(running_train_loss / len(train_dataloader))
    train_accuracies.append(train_accuracy)

except ValueError as ve:
    print(f"Error during training loop: {ve}")
    break

# Validation phase
model.eval()
running_val_loss = 0.0
correct = 0
total = 0
all_labels = []
all_probs = []

progress_bar = tqdm(val_dataloader, desc=f'Validating Epoch {epoch + 1}')

with torch.no_grad():
    try:
        # Loop through the validation batches
        for i, (image, extracted_features, pca_feature, metadata, labels) in enumerate(progress_bar):
            image, extracted_features, pca_feature, metadata, labels = image.to(device), extracted_features.to(device), pca_feature.to(device), metadata.to(device), labels.float().to(device)

```

```

        labels = labels.unsqueeze(1)

        probs = model(image, extracted_features, pca_feature,
↪metadata)

        loss = criterion(probs, labels)
        running_val_loss += loss.item()

        all_labels.extend(labels.cpu().detach().numpy())
        all_probs.extend(probs.cpu().detach().numpy())

        # Calculate binary predictions for validation accuracy
        predicted = (probs >= 0.5).float()
        total += labels.size(0)
        correct += (predicted == labels).sum().item()

        progress_bar.set_postfix(val_loss=running_val_loss / (i +
↪1))

    val_accuracy = 100 * correct / total
    val_loss = running_val_loss / len(val_dataloader)
    val_accuracies.append(val_accuracy)
    val_losses.append(val_loss)

    # Calculate AUROC
    try:
        valid_auroc = roc_auc_score(all_labels, all_probs)
    except ValueError as ve:
        print(f"AUROC Calculation Error: {ve}")
        valid_auroc = 0.0

    # Calculate partial AUC-above-TPR
    try:
        partial_auroc = score(np.array(all_labels), np.
↪array(all_probs), min_tpr=min_tpr)
    except ValueError as ve:
        print(f"Partial AUC Calculation Error: {ve}")
        partial_auroc = 0.0

    print(f'Epoch [{epoch}/{epochs}], Train Loss: {train_losses[-1]:
↪.4f}, Val Loss: {val_loss:.4f}, '
          f'Train Accuracy : {train_accuracy:.2f}%, Val Accuracy:
↪{val_accuracy:.2f}%, Val AUROC: {valid_auroc:.4f}, Partial AUROC:
↪{partial_auroc:.4f}')

    # Early stopping based on validation loss
    if val_loss < best_val_loss:

```

```

        best_val_loss = val_loss
        best_epoch = epoch + 1
        early_stopping_counter = 0
        torch.save(model.state_dict(), best_model_path)
    else:
        early_stopping_counter += 1

    if early_stopping_counter >= early_stopping_patience:
        print(f"Early stopping triggered at epoch {epoch}")
        break

except Exception as e:
    print(f"Error during validation loop: {e}")
    break

print(f"Best Epoch: {best_epoch}, Best Validation Loss: {best_val_loss:.4f}")
print('Training Complete')

# Plot training and validation loss
plt.figure(figsize=(10, 5))
plt.plot(train_losses, label='Train Loss')
plt.plot(val_losses, label='Validation Loss')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.title('Training and Validation Loss')
plt.legend()
plt.show()

# Plot training and validation accuracy
plt.figure(figsize=(10, 5))
plt.plot(train_accuracies, label='Train Accuracy')
plt.plot(val_accuracies, label='Validation Accuracy')
plt.xlabel('Epochs')
plt.ylabel('Accuracy (%)')
plt.title('Training and Validation Accuracy')
plt.legend()
plt.show()

# Generate classification report
try:
    print("Classification Report:")
    print(classification_report(all_labels, (np.array(all_probs) >= 0.5).
    ↪astype(int), target_names=['Class 0', 'Class 1']))
except Exception as e:
    print(f"Error generating classification report: {e}")

```

```
return model
```

## 0.4 Model training on training data and validation data

I opted to train a new model architecture to accommodate the integration of extracted features and PCA values as inputs for a multi-input model. This change in architecture is necessary to leverage these additional data inputs effectively and enhance the model's predictive capability.

```
[36]: device = "cuda" if torch.cuda.is_available() else "cpu"
model = CustomImageFeatureEfficientNet(extracted_feature_size=525,
    ↪pca_feature_size=70, metadata_size=9) # Assuming 9 features for metadata
model.to(device)
# Initialize optimizer
optimizer = optim.Adam(model.parameters(), lr=0.001)
# Define the loss function with the class weights
criterion = nn.BCELoss() # Binary classification loss
# Set the number of epochs
epochs = 20
best_model_path = "best_model.path"
```

EfficientNet loaded successfully.

```
/home/jupyter-sohka/.local/lib/python3.10/site-
packages/torchvision/models/_utils.py:208: UserWarning: The parameter
'pretrained' is deprecated since 0.13 and may be removed in the future, please
use 'weights' instead.
  warnings.warn(
/home/jupyter-sohka/.local/lib/python3.10/site-
packages/torchvision/models/_utils.py:223: UserWarning: Arguments other than a
weight enum or `None` for 'weights' are deprecated since 0.13 and may be removed
in the future. The current behavior is equivalent to passing
`weights=EfficientNet_B0_Weights.IMAGENET1K_V1`. You can also use
`weights=EfficientNet_B0_Weights.DEFAULT` to get the most up-to-date weights.
  warnings.warn(msg)
```

```
[37]: train_and_validate(model, effnet_train_dataloader, effnet_val_dataloader,
    ↪criterion, optimizer, epochs, device, best_model_path)
```

Epoch 1/20

```
Training Epoch 1: 100%|          | 131/131 [05:15<00:00, 2.41s/it,
train_loss=0.613]
Validating Epoch 1: 100%|          | 94/94 [00:49<00:00, 1.90it/s,
val_loss=0.502]
```

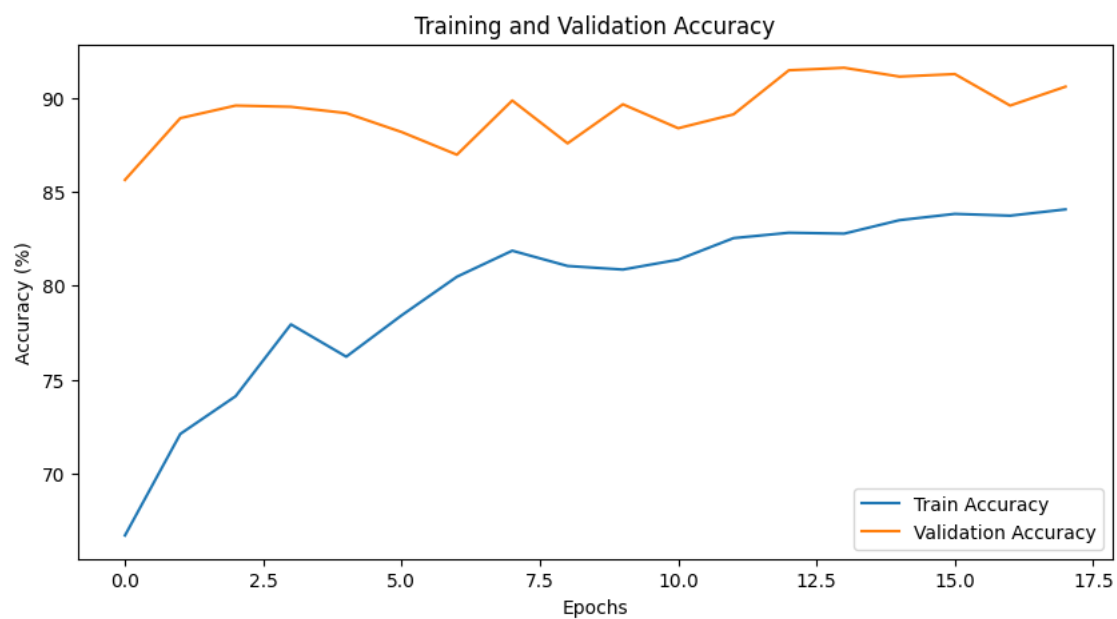
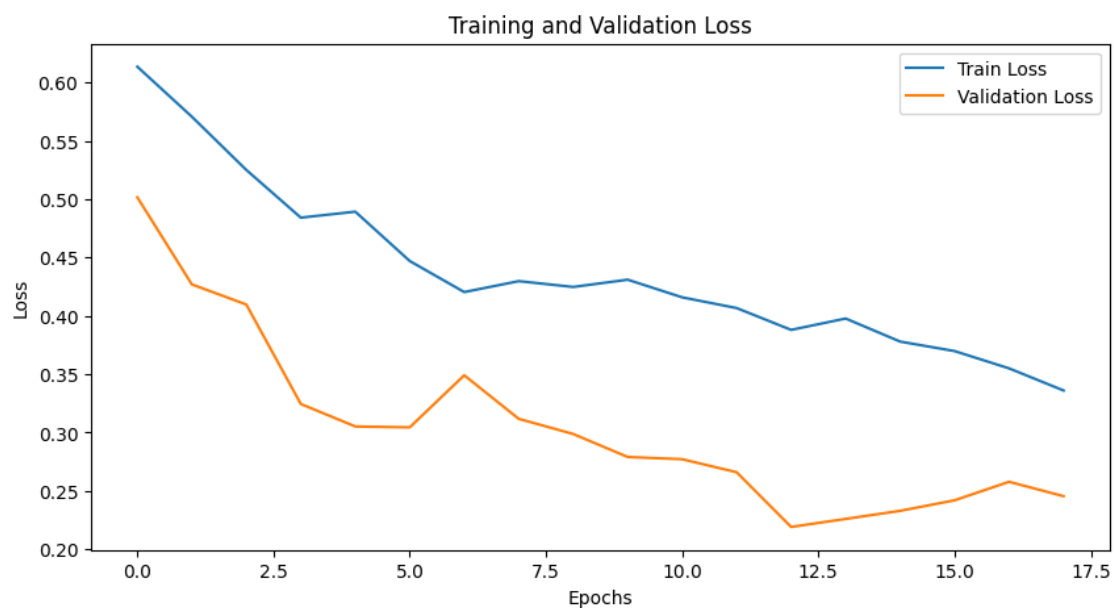
```
Epoch [0/20], Train Loss: 0.6134, Val Loss: 0.5015, Train Accuracy : 66.70%, Val
Accuracy: 85.64%, Val AUROC: 0.7202, Partial AUROC: 0.0439
Epoch 2/20
```

Training Epoch 2: 100%| | 131/131 [05:02<00:00, 2.31s/it,  
 train\_loss=0.571]  
 Validating Epoch 2: 100%| | 94/94 [00:44<00:00, 2.12it/s,  
 val\_loss=0.427]  
 Epoch [1/20], Train Loss: 0.5706, Val Loss: 0.4269, Train Accuracy : 72.11%, Val  
 Accuracy: 88.93%, Val AUROC: 0.7845, Partial AUROC: 0.0645  
 Epoch 3/20  
 Training Epoch 3: 100%| | 131/131 [05:51<00:00, 2.69s/it,  
 train\_loss=0.525]  
 Validating Epoch 3: 100%| | 94/94 [01:06<00:00, 1.42it/s,  
 val\_loss=0.41]  
 Epoch [2/20], Train Loss: 0.5250, Val Loss: 0.4097, Train Accuracy : 74.11%, Val  
 Accuracy: 89.60%, Val AUROC: 0.7987, Partial AUROC: 0.0714  
 Epoch 4/20  
 Training Epoch 4: 100%| | 131/131 [05:19<00:00, 2.44s/it,  
 train\_loss=0.484]  
 Validating Epoch 4: 100%| | 94/94 [00:44<00:00, 2.13it/s,  
 val\_loss=0.324]  
 Epoch [3/20], Train Loss: 0.4841, Val Loss: 0.3245, Train Accuracy : 77.94%, Val  
 Accuracy: 89.53%, Val AUROC: 0.8253, Partial AUROC: 0.0859  
 Epoch 5/20  
 Training Epoch 5: 100%| | 131/131 [05:15<00:00, 2.41s/it,  
 train\_loss=0.489]  
 Validating Epoch 5: 100%| | 94/94 [00:44<00:00, 2.11it/s,  
 val\_loss=0.305]  
 Epoch [4/20], Train Loss: 0.4892, Val Loss: 0.3052, Train Accuracy : 76.22%, Val  
 Accuracy: 89.19%, Val AUROC: 0.8441, Partial AUROC: 0.1042  
 Epoch 6/20  
 Training Epoch 6: 100%| | 131/131 [05:40<00:00, 2.60s/it,  
 train\_loss=0.447]  
 Validating Epoch 6: 100%| | 94/94 [00:43<00:00, 2.14it/s,  
 val\_loss=0.304]  
 Epoch [5/20], Train Loss: 0.4469, Val Loss: 0.3045, Train Accuracy : 78.42%, Val  
 Accuracy: 88.19%, Val AUROC: 0.8289, Partial AUROC: 0.0956  
 Epoch 7/20  
 Training Epoch 7: 100%| | 131/131 [05:14<00:00, 2.40s/it,  
 train\_loss=0.42]  
 Validating Epoch 7: 100%| | 94/94 [00:50<00:00, 1.86it/s,  
 val\_loss=0.349]  
 Epoch [6/20], Train Loss: 0.4203, Val Loss: 0.3491, Train Accuracy : 80.48%, Val  
 Accuracy: 86.98%, Val AUROC: 0.8373, Partial AUROC: 0.0920  
 Epoch 8/20

Training Epoch 8: 100%|        | 131/131 [05:10<00:00, 2.37s/it,  
 train\_loss=0.43]  
 Validating Epoch 8: 100%|        | 94/94 [00:43<00:00, 2.14it/s,  
 val\_loss=0.312]  
 Epoch [7/20], Train Loss: 0.4297, Val Loss: 0.3118, Train Accuracy : 81.87%, Val  
 Accuracy: 89.87%, Val AUROC: 0.8523, Partial AUROC: 0.1042  
 Epoch 9/20  
 Training Epoch 9: 100%|        | 131/131 [05:18<00:00, 2.43s/it,  
 train\_loss=0.425]  
 Validating Epoch 9: 100%|        | 94/94 [00:46<00:00, 2.01it/s,  
 val\_loss=0.299]  
 Epoch [8/20], Train Loss: 0.4247, Val Loss: 0.2988, Train Accuracy : 81.05%, Val  
 Accuracy: 87.58%, Val AUROC: 0.8513, Partial AUROC: 0.1092  
 Epoch 10/20  
 Training Epoch 10: 100%|        | 131/131 [05:25<00:00, 2.49s/it,  
 train\_loss=0.431]  
 Validating Epoch 10: 100%|        | 94/94 [00:45<00:00, 2.08it/s,  
 val\_loss=0.279]  
 Epoch [9/20], Train Loss: 0.4310, Val Loss: 0.2791, Train Accuracy : 80.86%, Val  
 Accuracy: 89.66%, Val AUROC: 0.8521, Partial AUROC: 0.1027  
 Epoch 11/20  
 Training Epoch 11: 100%|        | 131/131 [05:18<00:00, 2.43s/it,  
 train\_loss=0.416]  
 Validating Epoch 11: 100%|        | 94/94 [00:43<00:00, 2.14it/s,  
 val\_loss=0.277]  
 Epoch [10/20], Train Loss: 0.4158, Val Loss: 0.2772, Train Accuracy : 81.39%,  
 Val Accuracy: 88.39%, Val AUROC: 0.8581, Partial AUROC: 0.1050  
 Epoch 12/20  
 Training Epoch 12: 100%|        | 131/131 [05:13<00:00, 2.39s/it,  
 train\_loss=0.407]  
 Validating Epoch 12: 100%|        | 94/94 [00:52<00:00, 1.79it/s,  
 val\_loss=0.266]  
 Epoch [11/20], Train Loss: 0.4066, Val Loss: 0.2660, Train Accuracy : 82.54%,  
 Val Accuracy: 89.13%, Val AUROC: 0.8576, Partial AUROC: 0.1023  
 Epoch 13/20  
 Training Epoch 13: 100%|        | 131/131 [05:18<00:00, 2.43s/it,  
 train\_loss=0.388]  
 Validating Epoch 13: 100%|        | 94/94 [00:44<00:00, 2.13it/s,  
 val\_loss=0.219]  
 Epoch [12/20], Train Loss: 0.3880, Val Loss: 0.2191, Train Accuracy : 82.82%,  
 Val Accuracy: 91.48%, Val AUROC: 0.8625, Partial AUROC: 0.0991  
 Epoch 14/20



Training Epoch 14: 100%| | 131/131 [06:10<00:00, 2.83s/it,  
 train\_loss=0.398]  
 Validating Epoch 14: 100%| | 94/94 [00:46<00:00, 2.03it/s,  
 val\_loss=0.226]  
 Epoch [13/20], Train Loss: 0.3977, Val Loss: 0.2260, Train Accuracy : 82.78%,  
 Val Accuracy: 91.61%, Val AUROC: 0.8746, Partial AUROC: 0.1091  
 Epoch 15/20  
 Training Epoch 15: 100%| | 131/131 [05:09<00:00, 2.36s/it,  
 train\_loss=0.378]  
 Validating Epoch 15: 100%| | 94/94 [00:47<00:00, 1.98it/s,  
 val\_loss=0.233]  
 Epoch [14/20], Train Loss: 0.3779, Val Loss: 0.2329, Train Accuracy : 83.49%,  
 Val Accuracy: 91.14%, Val AUROC: 0.8660, Partial AUROC: 0.1090  
 Epoch 16/20  
 Training Epoch 16: 100%| | 131/131 [05:25<00:00, 2.48s/it,  
 train\_loss=0.37]  
 Validating Epoch 16: 100%| | 94/94 [00:43<00:00, 2.16it/s,  
 val\_loss=0.242]  
 Epoch [15/20], Train Loss: 0.3698, Val Loss: 0.2419, Train Accuracy : 83.83%,  
 Val Accuracy: 91.28%, Val AUROC: 0.8614, Partial AUROC: 0.1006  
 Epoch 17/20  
 Training Epoch 17: 100%| | 131/131 [05:33<00:00, 2.55s/it,  
 train\_loss=0.355]  
 Validating Epoch 17: 100%| | 94/94 [00:43<00:00, 2.17it/s,  
 val\_loss=0.258]  
 Epoch [16/20], Train Loss: 0.3550, Val Loss: 0.2578, Train Accuracy : 83.73%,  
 Val Accuracy: 89.60%, Val AUROC: 0.8662, Partial AUROC: 0.1025  
 Epoch 18/20  
 Training Epoch 18: 100%| | 131/131 [05:12<00:00, 2.39s/it,  
 train\_loss=0.336]  
 Validating Epoch 18: 100%| | 94/94 [00:45<00:00, 2.06it/s,  
 val\_loss=0.245]  
 Epoch [17/20], Train Loss: 0.3360, Val Loss: 0.2455, Train Accuracy : 84.07%,  
 Val Accuracy: 90.60%, Val AUROC: 0.8636, Partial AUROC: 0.1007  
 Early stopping triggered at epoch 17  
 Best Epoch: 13, Best Validation Loss: 0.2191  
 Training Complete



Classification Report:

	precision	recall	f1-score	support
Class 0	0.98	0.92	0.95	1431
Class 1	0.24	0.64	0.35	59
accuracy			0.91	1490

macro avg	0.61	0.78	0.65	1490
weighted avg	0.95	0.91	0.93	1490

```
[37]: CustomImageFeatureEfficientNet(
      (efficientnet): Sequential(
        (0): Sequential(
          (0): Conv2dNormActivation(
            (0): Conv2d(3, 32, kernel_size=(3, 3), stride=(2, 2), padding=(1, 1),
bias=False)
            (1): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
            (2): SiLU(inplace=True)
          )
          (1): Sequential(
            (0): MBConv(
              (block): Sequential(
                (0): Conv2dNormActivation(
                  (0): Conv2d(32, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1,
1), groups=32, bias=False)
                  (1): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
                  (2): SiLU(inplace=True)
                )
                (1): SqueezeExcitation(
                  (avgpool): AdaptiveAvgPool2d(output_size=1)
                  (fc1): Conv2d(32, 8, kernel_size=(1, 1), stride=(1, 1))
                  (fc2): Conv2d(8, 32, kernel_size=(1, 1), stride=(1, 1))
                  (activation): SiLU(inplace=True)
                  (scale_activation): Sigmoid()
                )
                (2): Conv2dNormActivation(
                  (0): Conv2d(32, 16, kernel_size=(1, 1), stride=(1, 1), bias=False)
                  (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
                )
              )
            )
            (stochastic_depth): StochasticDepth(p=0.0, mode=row)
          )
        )
        (2): Sequential(
          (0): MBConv(
            (block): Sequential(
              (0): Conv2dNormActivation(
                (0): Conv2d(16, 96, kernel_size=(1, 1), stride=(1, 1), bias=False)
                (1): BatchNorm2d(96, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
```

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        (2): SiLU(inplace=True)
    )
    (1): Conv2dNormActivation(
      (0): Conv2d(96, 96, kernel_size=(3, 3), stride=(2, 2), padding=(1,
1), groups=96, bias=False)
      (1): BatchNorm2d(96, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): SiLU(inplace=True)
    )
    (2): SqueezeExcitation(
      (avgpool): AdaptiveAvgPool2d(output_size=1)
      (fc1): Conv2d(96, 4, kernel_size=(1, 1), stride=(1, 1))
      (fc2): Conv2d(4, 96, kernel_size=(1, 1), stride=(1, 1))
      (activation): SiLU(inplace=True)
      (scale_activation): Sigmoid()
    )
    (3): Conv2dNormActivation(
      (0): Conv2d(96, 24, kernel_size=(1, 1), stride=(1, 1), bias=False)
      (1): BatchNorm2d(24, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
  )
  (stochastic_depth): StochasticDepth(p=0.0125, mode=row)
)
(1): MBConv(
  (block): Sequential(
    (0): Conv2dNormActivation(
      (0): Conv2d(24, 144, kernel_size=(1, 1), stride=(1, 1),
bias=False)
      (1): BatchNorm2d(144, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): SiLU(inplace=True)
    )
    (1): Conv2dNormActivation(
      (0): Conv2d(144, 144, kernel_size=(3, 3), stride=(1, 1),
padding=(1, 1), groups=144, bias=False)
      (1): BatchNorm2d(144, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): SiLU(inplace=True)
    )
    (2): SqueezeExcitation(
      (avgpool): AdaptiveAvgPool2d(output_size=1)
      (fc1): Conv2d(144, 6, kernel_size=(1, 1), stride=(1, 1))
      (fc2): Conv2d(6, 144, kernel_size=(1, 1), stride=(1, 1))
      (activation): SiLU(inplace=True)
      (scale_activation): Sigmoid()
    )
  )
)

```

```

        (3): Conv2dNormActivation(
          (0): Conv2d(144, 24, kernel_size=(1, 1), stride=(1, 1),
bias=False)
          (1): BatchNorm2d(24, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
        )
      )
      (stochastic_depth): StochasticDepth(p=0.025, mode=row)
    )
  (3): Sequential(
    (0): MBConv(
      (block): Sequential(
        (0): Conv2dNormActivation(
          (0): Conv2d(24, 144, kernel_size=(1, 1), stride=(1, 1),
bias=False)
          (1): BatchNorm2d(144, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
          (2): SiLU(inplace=True)
        )
        (1): Conv2dNormActivation(
          (0): Conv2d(144, 144, kernel_size=(5, 5), stride=(2, 2),
padding=(2, 2), groups=144, bias=False)
          (1): BatchNorm2d(144, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
          (2): SiLU(inplace=True)
        )
        (2): SqueezeExcitation(
          (avgpool): AdaptiveAvgPool2d(output_size=1)
          (fc1): Conv2d(144, 6, kernel_size=(1, 1), stride=(1, 1))
          (fc2): Conv2d(6, 144, kernel_size=(1, 1), stride=(1, 1))
          (activation): SiLU(inplace=True)
          (scale_activation): Sigmoid()
        )
        (3): Conv2dNormActivation(
          (0): Conv2d(144, 40, kernel_size=(1, 1), stride=(1, 1),
bias=False)
          (1): BatchNorm2d(40, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
        )
      )
      (stochastic_depth): StochasticDepth(p=0.037500000000000006, mode=row)
    )
  (1): MBConv(
    (block): Sequential(
      (0): Conv2dNormActivation(
        (0): Conv2d(40, 240, kernel_size=(1, 1), stride=(1, 1),

```

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bias=False)
    (1): BatchNorm2d(240, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): SiLU(inplace=True)
    )
    (1): Conv2dNormActivation(
    (0): Conv2d(240, 240, kernel_size=(5, 5), stride=(1, 1),
padding=(2, 2), groups=240, bias=False)
    (1): BatchNorm2d(240, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): SiLU(inplace=True)
    )
    (2): SqueezeExcitation(
    (avgpool): AdaptiveAvgPool2d(output_size=1)
    (fc1): Conv2d(240, 10, kernel_size=(1, 1), stride=(1, 1))
    (fc2): Conv2d(10, 240, kernel_size=(1, 1), stride=(1, 1))
    (activation): SiLU(inplace=True)
    (scale_activation): Sigmoid()
    )
    (3): Conv2dNormActivation(
    (0): Conv2d(240, 40, kernel_size=(1, 1), stride=(1, 1),
bias=False)
    (1): BatchNorm2d(40, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    )
    (stochastic_depth): StochasticDepth(p=0.05, mode=row)
    )
    )
    (4): Sequential(
    (0): MBConv(
    (block): Sequential(
    (0): Conv2dNormActivation(
    (0): Conv2d(40, 240, kernel_size=(1, 1), stride=(1, 1),
bias=False)
    (1): BatchNorm2d(240, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): SiLU(inplace=True)
    )
    (1): Conv2dNormActivation(
    (0): Conv2d(240, 240, kernel_size=(3, 3), stride=(2, 2),
padding=(1, 1), groups=240, bias=False)
    (1): BatchNorm2d(240, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): SiLU(inplace=True)
    )
    (2): SqueezeExcitation(

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        (avgpool): AdaptiveAvgPool2d(output_size=1)
        (fc1): Conv2d(240, 10, kernel_size=(1, 1), stride=(1, 1))
        (fc2): Conv2d(10, 240, kernel_size=(1, 1), stride=(1, 1))
        (activation): SiLU(inplace=True)
        (scale_activation): Sigmoid()
    )
    (3): Conv2dNormActivation(
        (0): Conv2d(240, 80, kernel_size=(1, 1), stride=(1, 1),
bias=False)
        (1): BatchNorm2d(80, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    )
    (stochastic_depth): StochasticDepth(p=0.0625, mode=row)
)
(1): MBConv(
    (block): Sequential(
        (0): Conv2dNormActivation(
            (0): Conv2d(80, 480, kernel_size=(1, 1), stride=(1, 1),
bias=False)
            (1): BatchNorm2d(480, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
            (2): SiLU(inplace=True)
        )
        (1): Conv2dNormActivation(
            (0): Conv2d(480, 480, kernel_size=(3, 3), stride=(1, 1),
padding=(1, 1), groups=480, bias=False)
            (1): BatchNorm2d(480, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
            (2): SiLU(inplace=True)
        )
    )
    (2): SqueezeExcitation(
        (avgpool): AdaptiveAvgPool2d(output_size=1)
        (fc1): Conv2d(480, 20, kernel_size=(1, 1), stride=(1, 1))
        (fc2): Conv2d(20, 480, kernel_size=(1, 1), stride=(1, 1))
        (activation): SiLU(inplace=True)
        (scale_activation): Sigmoid()
    )
    (3): Conv2dNormActivation(
        (0): Conv2d(480, 80, kernel_size=(1, 1), stride=(1, 1),
bias=False)
        (1): BatchNorm2d(80, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    )
    (stochastic_depth): StochasticDepth(p=0.07500000000000001, mode=row)
)

```

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(2): MBConv(
  (block): Sequential(
    (0): Conv2dNormActivation(
      (0): Conv2d(80, 480, kernel_size=(1, 1), stride=(1, 1),
bias=False)
      (1): BatchNorm2d(480, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): SiLU(inplace=True)
    )
    (1): Conv2dNormActivation(
      (0): Conv2d(480, 480, kernel_size=(3, 3), stride=(1, 1),
padding=(1, 1), groups=480, bias=False)
      (1): BatchNorm2d(480, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): SiLU(inplace=True)
    )
    (2): SqueezeExcitation(
      (avgpool): AdaptiveAvgPool2d(output_size=1)
      (fc1): Conv2d(480, 20, kernel_size=(1, 1), stride=(1, 1))
      (fc2): Conv2d(20, 480, kernel_size=(1, 1), stride=(1, 1))
      (activation): SiLU(inplace=True)
      (scale_activation): Sigmoid()
    )
    (3): Conv2dNormActivation(
      (0): Conv2d(480, 80, kernel_size=(1, 1), stride=(1, 1),
bias=False)
      (1): BatchNorm2d(80, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
  )
  (stochastic_depth): StochasticDepth(p=0.08750000000000001, mode=row)
)
(5): Sequential(
  (0): MBConv(
    (block): Sequential(
      (0): Conv2dNormActivation(
        (0): Conv2d(80, 480, kernel_size=(1, 1), stride=(1, 1),
bias=False)
        (1): BatchNorm2d(480, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
        (2): SiLU(inplace=True)
      )
      (1): Conv2dNormActivation(
        (0): Conv2d(480, 480, kernel_size=(5, 5), stride=(1, 1),
padding=(2, 2), groups=480, bias=False)
        (1): BatchNorm2d(480, eps=1e-05, momentum=0.1, affine=True,

```



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track_running_stats=True)
    (2): SiLU(inplace=True)
    )
    (2): SqueezeExcitation(
      (avgpool): AdaptiveAvgPool2d(output_size=1)
      (fc1): Conv2d(480, 20, kernel_size=(1, 1), stride=(1, 1))
      (fc2): Conv2d(20, 480, kernel_size=(1, 1), stride=(1, 1))
      (activation): SiLU(inplace=True)
      (scale_activation): Sigmoid()
    )
    (3): Conv2dNormActivation(
      (0): Conv2d(480, 112, kernel_size=(1, 1), stride=(1, 1),
bias=False)
      (1): BatchNorm2d(112, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
  )
  (stochastic_depth): StochasticDepth(p=0.1, mode=row)
)
(1): MBCConv(
  (block): Sequential(
    (0): Conv2dNormActivation(
      (0): Conv2d(112, 672, kernel_size=(1, 1), stride=(1, 1),
bias=False)
      (1): BatchNorm2d(672, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): SiLU(inplace=True)
    )
    (1): Conv2dNormActivation(
      (0): Conv2d(672, 672, kernel_size=(5, 5), stride=(1, 1),
padding=(2, 2), groups=672, bias=False)
      (1): BatchNorm2d(672, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): SiLU(inplace=True)
    )
    (2): SqueezeExcitation(
      (avgpool): AdaptiveAvgPool2d(output_size=1)
      (fc1): Conv2d(672, 28, kernel_size=(1, 1), stride=(1, 1))
      (fc2): Conv2d(28, 672, kernel_size=(1, 1), stride=(1, 1))
      (activation): SiLU(inplace=True)
      (scale_activation): Sigmoid()
    )
    (3): Conv2dNormActivation(
      (0): Conv2d(672, 112, kernel_size=(1, 1), stride=(1, 1),
bias=False)
      (1): BatchNorm2d(112, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)

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        )
    )
    (stochastic_depth): StochasticDepth(p=0.1125, mode=row)
)
(2): MBConv(
  (block): Sequential(
    (0): Conv2dNormActivation(
      (0): Conv2d(112, 672, kernel_size=(1, 1), stride=(1, 1),
bias=False)
      (1): BatchNorm2d(672, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): SiLU(inplace=True)
    )
    (1): Conv2dNormActivation(
      (0): Conv2d(672, 672, kernel_size=(5, 5), stride=(1, 1),
padding=(2, 2), groups=672, bias=False)
      (1): BatchNorm2d(672, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): SiLU(inplace=True)
    )
    (2): SqueezeExcitation(
      (avgpool): AdaptiveAvgPool2d(output_size=1)
      (fc1): Conv2d(672, 28, kernel_size=(1, 1), stride=(1, 1))
      (fc2): Conv2d(28, 672, kernel_size=(1, 1), stride=(1, 1))
      (activation): SiLU(inplace=True)
      (scale_activation): Sigmoid()
    )
    (3): Conv2dNormActivation(
      (0): Conv2d(672, 112, kernel_size=(1, 1), stride=(1, 1),
bias=False)
      (1): BatchNorm2d(112, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
  )
  (stochastic_depth): StochasticDepth(p=0.125, mode=row)
)
(6): Sequential(
  (0): MBConv(
    (block): Sequential(
      (0): Conv2dNormActivation(
        (0): Conv2d(112, 672, kernel_size=(1, 1), stride=(1, 1),
bias=False)
        (1): BatchNorm2d(672, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
        (2): SiLU(inplace=True)
      )
    )
  )

```

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        (1): Conv2dNormActivation(
          (0): Conv2d(672, 672, kernel_size=(5, 5), stride=(2, 2),
padding=(2, 2), groups=672, bias=False)
          (1): BatchNorm2d(672, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
          (2): SiLU(inplace=True)
        )
        (2): SqueezeExcitation(
          (avgpool): AdaptiveAvgPool2d(output_size=1)
          (fc1): Conv2d(672, 28, kernel_size=(1, 1), stride=(1, 1))
          (fc2): Conv2d(28, 672, kernel_size=(1, 1), stride=(1, 1))
          (activation): SiLU(inplace=True)
          (scale_activation): Sigmoid()
        )
        (3): Conv2dNormActivation(
          (0): Conv2d(672, 192, kernel_size=(1, 1), stride=(1, 1),
bias=False)
          (1): BatchNorm2d(192, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
        )
      )
      (stochastic_depth): StochasticDepth(p=0.1375, mode=row)
    )
    (1): MBConv(
      (block): Sequential(
        (0): Conv2dNormActivation(
          (0): Conv2d(192, 1152, kernel_size=(1, 1), stride=(1, 1),
bias=False)
          (1): BatchNorm2d(1152, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
          (2): SiLU(inplace=True)
        )
        (1): Conv2dNormActivation(
          (0): Conv2d(1152, 1152, kernel_size=(5, 5), stride=(1, 1),
padding=(2, 2), groups=1152, bias=False)
          (1): BatchNorm2d(1152, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
          (2): SiLU(inplace=True)
        )
        (2): SqueezeExcitation(
          (avgpool): AdaptiveAvgPool2d(output_size=1)
          (fc1): Conv2d(1152, 48, kernel_size=(1, 1), stride=(1, 1))
          (fc2): Conv2d(48, 1152, kernel_size=(1, 1), stride=(1, 1))
          (activation): SiLU(inplace=True)
          (scale_activation): Sigmoid()
        )
        (3): Conv2dNormActivation(

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        (0): Conv2d(1152, 192, kernel_size=(1, 1), stride=(1, 1),
bias=False)
        (1): BatchNorm2d(192, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    )
    (stochastic_depth): StochasticDepth(p=0.15000000000000002, mode=row)
)
(2): MBConv(
  (block): Sequential(
    (0): Conv2dNormActivation(
      (0): Conv2d(192, 1152, kernel_size=(1, 1), stride=(1, 1),
bias=False)
      (1): BatchNorm2d(1152, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): SiLU(inplace=True)
    )
    (1): Conv2dNormActivation(
      (0): Conv2d(1152, 1152, kernel_size=(5, 5), stride=(1, 1),
padding=(2, 2), groups=1152, bias=False)
      (1): BatchNorm2d(1152, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): SiLU(inplace=True)
    )
    (2): SqueezeExcitation(
      (avgpool): AdaptiveAvgPool2d(output_size=1)
      (fc1): Conv2d(1152, 48, kernel_size=(1, 1), stride=(1, 1))
      (fc2): Conv2d(48, 1152, kernel_size=(1, 1), stride=(1, 1))
      (activation): SiLU(inplace=True)
      (scale_activation): Sigmoid()
    )
    (3): Conv2dNormActivation(
      (0): Conv2d(1152, 192, kernel_size=(1, 1), stride=(1, 1),
bias=False)
      (1): BatchNorm2d(192, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
  )
  (stochastic_depth): StochasticDepth(p=0.1625, mode=row)
)
(3): MBConv(
  (block): Sequential(
    (0): Conv2dNormActivation(
      (0): Conv2d(192, 1152, kernel_size=(1, 1), stride=(1, 1),
bias=False)
      (1): BatchNorm2d(1152, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)

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        (2): SiLU(inplace=True)
    )
    (1): Conv2dNormActivation(
        (0): Conv2d(1152, 1152, kernel_size=(5, 5), stride=(1, 1),
padding=(2, 2), groups=1152, bias=False)
        (1): BatchNorm2d(1152, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
        (2): SiLU(inplace=True)
    )
    (2): SqueezeExcitation(
        (avgpool): AdaptiveAvgPool2d(output_size=1)
        (fc1): Conv2d(1152, 48, kernel_size=(1, 1), stride=(1, 1))
        (fc2): Conv2d(48, 1152, kernel_size=(1, 1), stride=(1, 1))
        (activation): SiLU(inplace=True)
        (scale_activation): Sigmoid()
    )
    (3): Conv2dNormActivation(
        (0): Conv2d(1152, 192, kernel_size=(1, 1), stride=(1, 1),
bias=False)
        (1): BatchNorm2d(192, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    )
    (stochastic_depth): StochasticDepth(p=0.17500000000000002, mode=row)
)
(7): Sequential(
  (0): MBConv(
    (block): Sequential(
      (0): Conv2dNormActivation(
        (0): Conv2d(192, 1152, kernel_size=(1, 1), stride=(1, 1),
bias=False)
        (1): BatchNorm2d(1152, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
        (2): SiLU(inplace=True)
      )
      (1): Conv2dNormActivation(
        (0): Conv2d(1152, 1152, kernel_size=(3, 3), stride=(1, 1),
padding=(1, 1), groups=1152, bias=False)
        (1): BatchNorm2d(1152, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
        (2): SiLU(inplace=True)
      )
    )
    (2): SqueezeExcitation(
      (avgpool): AdaptiveAvgPool2d(output_size=1)
      (fc1): Conv2d(1152, 48, kernel_size=(1, 1), stride=(1, 1))
      (fc2): Conv2d(48, 1152, kernel_size=(1, 1), stride=(1, 1))
    )
  )
)

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```

        (activation): SiLU(inplace=True)
        (scale_activation): Sigmoid()
    )
    (3): Conv2dNormActivation(
      (0): Conv2d(1152, 320, kernel_size=(1, 1), stride=(1, 1),
bias=False)
      (1): BatchNorm2d(320, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
  )
  (stochastic_depth): StochasticDepth(p=0.1875, mode=row)
)
)
(8): Conv2dNormActivation(
  (0): Conv2d(320, 1280, kernel_size=(1, 1), stride=(1, 1), bias=False)
  (1): BatchNorm2d(1280, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
  (2): SiLU(inplace=True)
)
)
(1): AdaptiveAvgPool2d(output_size=1)
)
(fc_image): Sequential(
  (0): Linear(in_features=1280, out_features=1024, bias=True)
  (1): ReLU()
  (2): BatchNorm1d(1024, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
  (3): Dropout(p=0.8, inplace=False)
  (4): Linear(in_features=1024, out_features=512, bias=True)
  (5): ReLU()
  (6): BatchNorm1d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
)
(fc_extracted_features): Sequential(
  (0): Linear(in_features=525, out_features=512, bias=True)
  (1): ReLU()
  (2): BatchNorm1d(512, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
  (3): Dropout(p=0.8, inplace=False)
  (4): Linear(in_features=512, out_features=256, bias=True)
  (5): ReLU()
  (6): BatchNorm1d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
)
(fc_pca_features): Sequential(
  (0): Linear(in_features=70, out_features=256, bias=True)
  (1): ReLU()

```

```

        (2): BatchNorm1d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
        (3): Dropout(p=0.8, inplace=False)
        (4): Linear(in_features=256, out_features=128, bias=True)
        (5): ReLU()
        (6): BatchNorm1d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    (fc_metadata): Sequential(
        (0): Linear(in_features=9, out_features=128, bias=True)
        (1): ReLU()
        (2): BatchNorm1d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
        (3): Dropout(p=0.8, inplace=False)
        (4): Linear(in_features=128, out_features=64, bias=True)
        (5): ReLU()
        (6): BatchNorm1d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    )
    (fc_combined): Sequential(
        (0): Linear(in_features=960, out_features=256, bias=True)
        (1): ReLU()
        (2): BatchNorm1d(256, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
        (3): Dropout(p=0.8, inplace=False)
        (4): Linear(in_features=256, out_features=64, bias=True)
        (5): ReLU()
        (6): Linear(in_features=64, out_features=1, bias=True)
    )
)

```

## 0.5 Model performance on test data

```

[50]: # Instantiate the model with the correct variable names
final_model = CustomImageFeatureEfficientNet(extracted_feature_size=525,
↪pca_feature_size=70, metadata_size=9)
final_model_path = "best_model.path"

# Load the model's state dictionary with error handling
try:
    final_model.load_state_dict(torch.load(final_model_path, map_location=torch.
↪device("cpu")))
    print("Model loaded successfully.")
except FileNotFoundError:
    print(f"Error: Model file not found at {final_model_path}")
    raise

```

```

except Exception as e:
    print(f"Error loading model: {e}")
    raise

# Set the model to evaluation mode
final_model.eval()

# Initialize lists to store true labels and predicted probabilities
all_labels, all_probs = [], []
misclassified_images = []

# Disable gradient calculation for evaluation to save memory and computation
with torch.no_grad():
    try:
        for i, (image, extracted_features, pca_features, metadata, labels) in
            ↪ enumerate(effnet_test_dataloader):
            # Move data to the specified device
            image, extracted_features, pca_features, metadata, labels = (
                image.to(device),
                extracted_features.to(device),
                pca_features.to(device),
                metadata.to(device),
                labels.float().to(device).unsqueeze(1) # Ensure labels have
            ↪ the correct shape
            )

            # Get the model's predictions
            probs = final_model(image, extracted_features, pca_features,
            ↪ metadata)

            # Store true labels and predicted probabilities for analysis
            all_labels.extend(labels.cpu().numpy())
            all_probs.extend(probs.cpu().numpy())

            # Calculate binary predictions (0 or 1)
            predicted = (probs > 0.5).float()
            misclassified_indices = (predicted != labels).squeeze().cpu().
            ↪ numpy()

            # Identify misclassified images and store them
            for j, is_misclassified in enumerate(misclassified_indices):
                if is_misclassified and labels[j].cpu().item() == 1:
                    misclassified_images.append((image[j].cpu(), labels[j].
            ↪ cpu(), probs[j].item())) # .item() converts the tensor to a float

            # Calculate partial AUROC for the predictions
            partial_auroc = score(np.array(all_labels), np.array(all_probs))

```



```

print(f'The partial AUROC of the final model on the test image is_
↳{partial_auroc:.4f}')

# Print a classification report
print(classification_report(all_labels, (np.array(all_probs) >= 0.5).
↳astype(int), target_names=["Class 0", "Class 1"]))

# Display a few misclassified images if any
# Display a few misclassified images if any
if misclassified_images:
    print(f"Total misclassified images with true label 1:_
↳{len(misclassified_images)}")
    for i, (img, true_label, pred_prob) in_
↳enumerate(misclassified_images[:5]):
        img = img.permute(1, 2, 0).numpy() # Convert from PyTorch_
↳tensor format to NumPy array

        # Ensure the image is within the range [0, 1] for floats
        if img.dtype == np.float32 or img.dtype == np.float64:
            img = np.clip((img - img.min()) / (img.max() - img.min()),_
↳0, 1)

        # Ensure the image is within the range [0, 255] for integers
        elif img.dtype == np.int32 or img.dtype == np.int64:
            img = np.clip(img, 0, 255).astype(np.uint8)

        plt.imshow(img, cmap="gray" if img.shape[-1] == 1 else None) #_
↳Display as grayscale if needed
        plt.title(f'True Label: {true_label}, Predicted Prob:_
↳{pred_prob:.4f}')
        plt.axis('off')
        plt.show()

except Exception as e:
    print(f"Error during model evaluation: {e}")

```

```

/home/jupyter-sohka/.local/lib/python3.10/site-
packages/torchvision/models/_utils.py:208: UserWarning: The parameter
'pretrained' is deprecated since 0.13 and may be removed in the future, please
use 'weights' instead.
  warnings.warn(
/home/jupyter-sohka/.local/lib/python3.10/site-
packages/torchvision/models/_utils.py:223: UserWarning: Arguments other than a
weight enum or `None` for 'weights' are deprecated since 0.13 and may be removed

```

in the future. The current behavior is equivalent to passing  
``weights=EfficientNet_B0_Weights.IMAGENET1K_V1``. You can also use  
``weights=EfficientNet_B0_Weights.DEFAULT`` to get the most up-to-date weights.  
`warnings.warn(msg)`  
/tmp/ipykernel\_1621439/2933086743.py:7: FutureWarning: You are using  
``torch.load`` with ``weights_only=False`` (the current default value), which uses  
the default pickle module implicitly. It is possible to construct malicious  
pickle data which will execute arbitrary code during unpickling (See  
<https://github.com/pytorch/pytorch/blob/main/SECURITY.md#untrusted-models> for  
more details). In a future release, the default value for ``weights_only`` will be  
flipped to ``True``. This limits the functions that could be executed during  
unpickling. Arbitrary objects will no longer be allowed to be loaded via this  
mode unless they are explicitly allowlisted by the user via  
``torch.serialization.add_safe_globals``. We recommend you start setting  
``weights_only=True`` for any use case where you don't have full control of the  
loaded file. Please open an issue on GitHub for any issues related to this  
experimental feature.

```
final_model.load_state_dict(torch.load(final_model_path,
map_location=torch.device("cpu")))
```

EfficientNet loaded successfully.

Model loaded successfully.

The partial AUROC of the final model on the test image is 0.1226

	precision	recall	f1-score	support
Class 0	0.98	0.92	0.95	1431
Class 1	0.23	0.56	0.33	59
accuracy			0.91	1490
macro avg	0.61	0.74	0.64	1490
weighted avg	0.95	0.91	0.93	1490

Total misclassified images with true label 1: 26

True Label: tensor([1.]), Predicted Prob: 0.3641



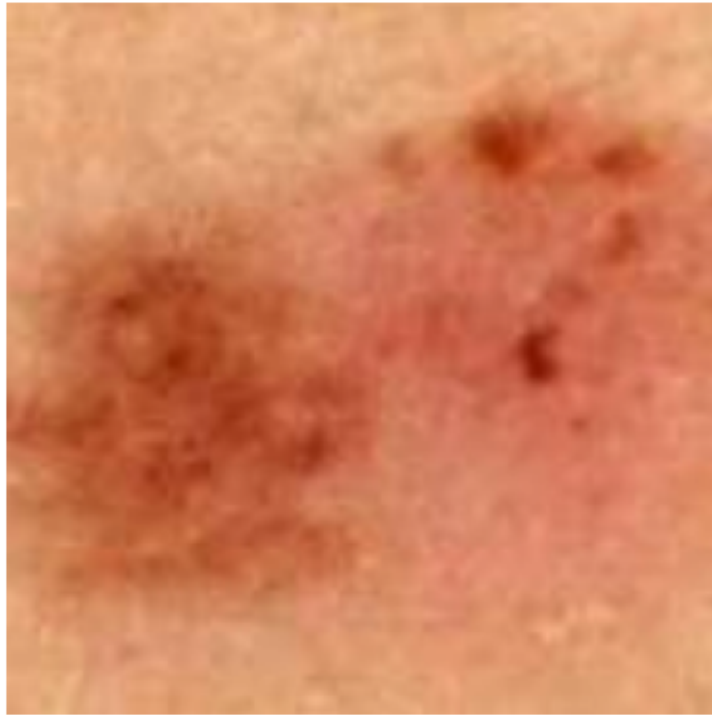
True Label: tensor([1.]), Predicted Prob: 0.4236



True Label: tensor([1.]), Predicted Prob: 0.0758



True Label: tensor([1.]), Predicted Prob: 0.2860



True Label: tensor([1.]), Predicted Prob: 0.2469



By analyzing the training and validation loss at the best epoch, as well as the test data performance metrics (with a key metric value partial AUROC of 0.124 and a recall for Class 1 at 0.64), I conclude that the newly added features and augmentations did not significantly improve the predictive results. Compared to the previous week's winning model using the original training data, which had a recall for Class 1 of 0.61 and a partial AUROC of 0.136, there was only a slight decrease in key metric.

[ ]:

[ ]: