Install Required Libraries

```
import warnings
warnings.filterwarnings('ignore')

!pip install opencv-python

Requirement already satisfied: opencv-python in
/usr/local/lib/python3.10/dist-packages (4.8.0.76)
Requirement already satisfied: numpy>=1.21.2 in
/usr/local/lib/python3.10/dist-packages (from opencv-python) (1.25.2)

!pip install keras-vggface

Collecting keras-vggface
  Downloading keras_vggface-0.6-py3-none-any.whl (8.3 kB)
Requirement already satisfied: numpy>=1.9.1 in
/usr/local/lib/python3.10/dist-packages (from keras-vggface) (1.25.2)
Requirement already satisfied: scipy>=0.14 in
/usr/local/lib/python3.10/dist-packages (from keras-vggface) (1.11.4)
Requirement already satisfied: h5py in /usr/local/lib/python3.10/dist-
packages (from keras-vggface) (3.9.0)
Requirement already satisfied: pillow in
/usr/local/lib/python3.10/dist-packages (from keras-vggface) (9.4.0)
Requirement already satisfied: keras in
/usr/local/lib/python3.10/dist-packages (from keras-vggface) (2.15.0)
Requirement already satisfied: six>=1.9.0 in
/usr/local/lib/python3.10/dist-packages (from keras-vggface) (1.16.0)
Requirement already satisfied: pyyaml in
/usr/local/lib/python3.10/dist-packages (from keras-vggface) (6.0.1)
Installing collected packages: keras-vggface
Successfully installed keras-vggface-0.6

!pip install keras==2.12
!pip install git+https://github.com/rcmalli/keras-vggface.git

Collecting keras==2.12
  Downloading keras-2.12.0-py2.py3-none-any.whl (1.7 MB)
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━━━━━ ━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 0.2/1.7 MB 7.6 MB/s eta
0:00:01 ━━━━━━━━━━━━━━━━━ ━━━━━━━━━━━━━━━━━━━━━━ 0.8/1.7 MB 11.3 MB/s
eta 0:00:01 ━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ ━━━━━━━━ 1.4/1.7 MB 13.5
MB/s eta 0:00:01 ━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 1.7/1.7 MB
13.2 MB/s eta 0:00:00
pting uninstall: keras
    Found existing installation: keras 2.15.0
    Uninstalling keras-2.15.0:
      Successfully uninstalled keras-2.15.0
ERROR: pip's dependency resolver does not currently take into account
```

```
all the packages that are installed. This behaviour is the source of
the following dependency conflicts.
tensorflow 2.15.0 requires keras<2.16,>=2.15.0, but you have keras
2.12.0 which is incompatible.
Successfully installed keras-2.12.0
Collecting git+https://github.com/rcmalli/keras-vggface.git
  Cloning https://github.com/rcmalli/keras-vggface.git to /tmp/pip-
req-build-u62vd2d2
  Running command git clone --filter=blob:none --quiet
https://github.com/rcmalli/keras-vggface.git /tmp/pip-req-build-
u62vd2d2
  Resolved https://github.com/rcmalli/keras-vggface.git to commit
bee35376e76e35d00aeec503f2f242611a97b38a
  Preparing metadata (setup.py) ... ent already satisfied:
numpy>=1.9.1 in /usr/local/lib/python3.10/dist-packages (from keras-
vggface==0.6) (1.25.2)
Requirement already satisfied: scipy>=0.14 in
/usr/local/lib/python3.10/dist-packages (from keras-vggface==0.6)
(1.11.4)
Requirement already satisfied: h5py in /usr/local/lib/python3.10/dist-
packages (from keras-vggface==0.6) (3.9.0)
Requirement already satisfied: pillow in
/usr/local/lib/python3.10/dist-packages (from keras-vggface==0.6)
(9.4.0)
Requirement already satisfied: keras in
/usr/local/lib/python3.10/dist-packages (from keras-vggface==0.6)
(2.12.0)
Requirement already satisfied: six>=1.9.0 in
/usr/local/lib/python3.10/dist-packages (from keras-vggface==0.6)
(1.16.0)
Requirement already satisfied: pyyaml in
/usr/local/lib/python3.10/dist-packages (from keras-vggface==0.6)
(6.0.1)
```

```
!pip install keras_applications --no-deps
filename =
"/usr/local/lib/python3.10/dist-packages/keras_vggface/models.py"
text = open(filename).read()
open(filename, "w+").write(text.replace('keras.engine.topology',
'tensorflow.keras.utils'))
import tensorflow as tf
```

```
Collecting keras_applications
  Downloading Keras_Applications-1.0.8-py3-none-any.whl (50 kB)
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 0.0/50.7 kB ? eta -:--:--
━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 50.7/50.7 kB 2.3 MB/s eta
0:00:00
```

```
import os
import urllib.request
```

```python
from zipfile import ZipFile
import tarfile
import cv2
import dlib
import numpy as np
import matplotlib.pyplot as plt
import bz2
import shutil
import gdown
import gzip
from skimage import io
import pickle

from keras_vggface.vggface import VGGFace
from keras.layers import Input, Conv2D, UpSampling2D, Flatten, Dense,
Reshape, Layer
from keras.models import Model
from keras.optimizers import Adam
from keras_vggface.utils import preprocess_input
```

Download Dataset

```python
# Function to download and extract the dataset
def download_and_extract(dataset_url,
download_path='datasets/normal_face.tgz',
extract_path='datasets/normal_faces', remove_file = True):
    if not os.path.exists(extract_path):
        os.makedirs(os.path.dirname(download_path), exist_ok = True)
        print("Downloading dataset...")
        urllib.request.urlretrieve(dataset_url, download_path)
        print("Download complete.")

        # Extract the zip file
        print("Extracting dataset...")
        with tarfile.open(download_path, 'r:gz') as tar:
            tar.extractall(path=os.path.dirname(extract_path))
        print("Extraction complete.")

        # Optionally, remove the zip file
        if remove_file:
            os.remove(download_path)
            print('Tar.gz file removed.')

        print("Dataset ready.")
    else:
        print("Dataset already downloaded and extracted.")
```

```
# URL of the LFW dataset
lfw_url = 'http://vis-www.cs.umass.edu/lfw/lfw.tgz'
# Set download to false if the download is not needed
download = True
if download:
    download_and_extract(dataset_url = lfw_url, remove_file = False)
    download = False
```

```
Downloading dataset...
Download complete.
Extracting dataset...
Extraction complete.
Dataset ready.
```

```
## RUN WITH CAUTION ##
def delete_non_empty_directory(dir_path, delete = False):
    if delete:
      # Check if the directory exists
      if os.path.exists(dir_path):
        # Remove the directory and all its contents
        shutil.rmtree(dir_path)
        print(f"Directory '{dir_path}' has been removed along with all its contents.")
      else:
        print(f"The directory '{dir_path}' does not exist.")
    else:
      print('No directory deleted.')

# Usage
directory_to_delete = "modified_datasets"
delete_non_empty_directory(directory_to_delete, False)
```

```
Directory 'modified_datasets' has been removed along with all its contents.
```

Blurring features

```
def download_dlib_model(url, bz2_filename, dat_filename, remove_file = False):
    # Check if the decompressed .dat file already exists
    if not os.path.isfile(dat_filename):
        # Check if the compressed .bz2 file already exists
        if not os.path.isfile(bz2_filename):
            print(f"Downloading {bz2_filename}...")
            urllib.request.urlretrieve(url, bz2_filename)
            print(f"Downloaded {bz2_filename}.")

        # Decompress the .bz2 file to get the .dat file
```

```
        print(f"Decompressing {bz2_filename} to get
{dat_filename}...")
        with bz2.BZ2File(bz2_filename, 'rb') as f_in:
            with open(dat_filename, 'wb') as f_out:
                shutil.copyfileobj(f_in, f_out)
        print(f"Decompressed to {dat_filename}.")

        # Optionally, remove the .bz2 file after decompression
        if remove_file:
          os.remove(bz2_filename)
          print(f"Removed compressed file {bz2_filename}.")
    else:
        print(f"{dat_filename} already exists. No download needed.")

# URL to the dlib pre-trained facial landmark predictor
dlib_model_url =
"http://dlib.net/files/shape_predictor_68_face_landmarks.dat.bz2"
# Filename of the compressed model
compressed_file_name = "shape_predictor_68_face_landmarks.dat.bz2"
# Filename of the decompressed model
model_file_name = "shape_predictor_68_face_landmarks.dat"

# Call the function to download and decompress the model
download_dlib_model(dlib_model_url, compressed_file_name,
model_file_name)
```

```
Downloading shape_predictor_68_face_landmarks.dat.bz2...
Downloaded shape_predictor_68_face_landmarks.dat.bz2.
Decompressing shape_predictor_68_face_landmarks.dat.bz2 to get
shape_predictor_68_face_landmarks.dat...
Decompressed to shape_predictor_68_face_landmarks.dat.
```

```
# Initialize dlib face detector and landmark predictor
detector = dlib.get_frontal_face_detector()
predictor =
dlib.shape_predictor('shape_predictor_68_face_landmarks.dat')

def blur_feature(image, landmarks, feature_indices, feature_type):
    '''
    Applies a blurring effect to specific features on the face by
fitting an ellipse around the landmarks.

    Parameters:
    image (numpy.ndarray): The original image.
    landmarks (dlib.full_object_detection): Facial landmarks detected
by dlib predictor.
    feature_indices (list of int): Indices of the landmarks that
define the region to blur.
    feature_type (str): The type of feature to blur ('eyes', 'nose',
'mouth').
```

```
    Returns:
    numpy.ndarray: The image with the specified feature blurred.
    '''

    # Create a mask to match the image dimensions, single channel for
grayscale
    mask = np.zeros_like(image[:, :, 0])

    # Collect points from the landmarks based on the provided indices
    feature_points = np.array([(landmarks.part(n).x,
landmarks.part(n).y) for n in feature_indices], dtype=np.int32)

    # Generate a convex hull (the smallest convex polygon containing
all points) for the feature
    hull = cv2.convexHull(feature_points)

    # Fit a rotated rectangle to the convex hull of the feature
points, which provides a better fit than an ellipse
    rect = cv2.minAreaRect(hull)
    box = cv2.boxPoints(rect)
    box = np.int32(box)

    # Depending on the feature, adjust the box dimensions
    if feature_type in ['eyes', 'mouth']:
        # For the eyes and mouth, expand the box horizontally
        center, size, angle = rect
        size = (size[0] * 1.4, size[1] * 1.2)  # Increase the size a
bit for better coverage
        rect = (center, size, angle)
        box = cv2.boxPoints(rect)
        box = np.int32(box)

    elif feature_type == 'nose':
        # For the nose, expand the box vertically
        center, size, angle = rect
        size = (size[0] * 1.2, size[1] * 1.4)
        rect = (center, size, angle)
        box = cv2.boxPoints(rect)
        box = np.int32(box)

    # Draw the fitted box on the mask
    cv2.drawContours(mask, [box], 0, (255, 255, 255), -1)

    # Apply Gaussian blur to the image
    blurred_image = cv2.GaussianBlur(image, (51, 51), 0)

    # Combine the original and blurred images using the mask
    combined_image = np.where(mask[..., None].astype(bool),
blurred_image, image)
```

```
    return combined_image

def mask_feature(image, landmarks, feature_indices, feature_type):
    '''
    Applies a black mask to specific features on the face by fitting a
rotated rectangle around the landmarks.

    Parameters:
    image (numpy.ndarray): The original image.
    landmarks (dlib.full_object_detection): Facial landmarks detected
by dlib predictor.
    feature_indices (list of int): Indices of the landmarks that
define the region to mask.
    feature_type (str): The type of feature to mask ('eyebrows',
'eyes', 'nose', 'mouth').

    Returns:
    numpy.ndarray: The image with the specified feature masked with a
black box.
    '''

    # Create a mask to match the image dimensions, single channel for
grayscale
    mask = np.zeros_like(image[:, :, 0])

    # Collect points from the landmarks based on the provided indices
    feature_points = np.array([(landmarks.part(n).x,
landmarks.part(n).y) for n in feature_indices], dtype=np.int32)

    # Generate a convex hull for the feature
    hull = cv2.convexHull(feature_points)

    # Fit a rotated rectangle to the convex hull of the feature points
    rect = cv2.minAreaRect(hull)
    box = cv2.boxPoints(rect)
    box = np.int32(box)

    # Adjust the box dimensions based on the feature
    if feature_type in ['eyes', 'mouth', 'eyebrows']:
        # For the eyes, mouth, and eyebrows, expand the box slightly
for better coverage
        center, size, angle = rect
        if feature_type == 'eyebrows':
            size = (size[0] * 1.2, size[1] * 1.5)  # Eyebrows are
thinner but wider
        else:
            size = (size[0] * 1.4, size[1] * 1.2)  # Eyes and mouth
        rect = (center, size, angle)
        box = cv2.boxPoints(rect)
```

```
        box = np.int32(box)

    elif feature_type == 'nose':
        # For the nose, expand the box more vertically
        center, size, angle = rect
        size = (size[0] * 1.2, size[1] * 1.4)
        rect = (center, size, angle)
        box = cv2.boxPoints(rect)
        box = np.int32(box)

    # Draw the fitted box on the mask with white color
    cv2.drawContours(mask, [box], 0, (255), -1)

    # Mask the feature by setting the pixels inside the mask to black
in the original image
    image[mask == 255] = [0, 0, 0]  # Set to black

    return image

from skimage import io
detector = dlib.get_frontal_face_detector()
predictor_path = 'shape_predictor_68_face_landmarks.dat'  # Path to
the facial landmark predictor file
predictor = dlib.shape_predictor(predictor_path)  # Load the facial
landmark predictor

# Function to save an image
def save_image(image, path, filename):
    if not os.path.exists(path):
        os.makedirs(path)
    cv2.imwrite(os.path.join(path, filename), image)

def check_feature_visibility(landmarks, indices):
    """ Check if all indices in a feature have detectable landmarks
"""
    return all(landmarks.part(i) for i in indices)

def create_and_save_masked_datasets(base_path, save_path,
target_size=(224, 224)):
    labels = {'normal': [], 'masked_eyebrows': [], 'masked_eyes': [],
'masked_nose': [], 'masked_mouth': []}

    for individual in os.listdir(os.path.join(base_path, 'lfw')):
        individual_path = os.path.join(base_path, 'lfw', individual)

        for image_file in os.listdir(individual_path):
            if image_file.lower().endswith('.jpg'):
                image_path = os.path.join(individual_path, image_file)
                image = io.imread(image_path)
                image = cv2.resize(image, target_size)
```

```
                gray = cv2.cvtColor(image, cv2.COLOR_RGB2GRAY)

                faces = detector(gray, 1)
                face_detected = False
                if len(faces) > 0:
                    face = faces[0]
                    landmarks = predictor(gray, face)
                    # Indices for eyebrows, eyes, nose, and mouth
features
                    eyebrows_indices = list(range(17, 27))  # Add
eyebrows
                    eyes_indices = list(range(36, 42)) +
list(range(42, 48))
                    nose_indices = list(range(27, 36))
                    mouth_indices = list(range(48, 68))

                    # Check visibility of each feature
                    has_eyebrows = check_feature_visibility(landmarks,
eyebrows_indices)
                    has_eyes = check_feature_visibility(landmarks,
eyes_indices)
                    has_nose = check_feature_visibility(landmarks,
nose_indices)
                    has_mouth = check_feature_visibility(landmarks,
mouth_indices)

                    if has_eyebrows and has_eyes and has_nose and
has_mouth:
                        face_detected = True
                        masked_eyebrows = mask_feature(image.copy(),
landmarks, eyebrows_indices, 'eyebrows')
                        masked_eyes = mask_feature(image.copy(),
landmarks, eyes_indices, 'eyes')
                        masked_nose = mask_feature(image.copy(),
landmarks, nose_indices, 'nose')
                        masked_mouth = mask_feature(image.copy(),
landmarks, mouth_indices, 'mouth')
                    else:
                        masked_eyebrows, masked_eyes, masked_nose,
masked_mouth = image.copy(), image.copy(), image.copy(), image.copy()

                save_image(image, os.path.join(save_path, 'normal'),
image_file)
                save_image(masked_eyebrows, os.path.join(save_path,
'masked_eyebrows'), image_file)
                save_image(masked_eyes, os.path.join(save_path,
'masked_eyes'), image_file)
                save_image(masked_nose, os.path.join(save_path,
'masked_nose'), image_file)
                save_image(masked_mouth, os.path.join(save_path,
```

```
'masked_mouth'), image_file)

                # Update labels based on the feature visibility
                face_label = 1 if face_detected else 0
                labels['normal'].append(face_label)
                labels['masked_eyebrows'].append(face_label)
                labels['masked_eyes'].append(face_label)
                labels['masked_nose'].append(face_label)
                labels['masked_mouth'].append(face_label)

    for key in labels:
        labels_path = os.path.join(save_path, key)
        if not os.path.exists(labels_path):
            os.makedirs(labels_path)
        np.save(os.path.join(labels_path, 'labels.npy'),
np.array(labels[key]))

# Example usage of the function
base_path = 'datasets'  # Base path to the LFW dataset
save_path = 'modified_datasets'  # Path where you want to save the new
datasets
create_and_save_masked_datasets(base_path, save_path)
```

Loading Images for Training

```
def load_images_from_directory(directory, label_file,
target_size=(224, 224)):
    """
    Loads images from a directory and their corresponding labels from
a .npy file.
    Assumes that images are named in such a way that sorting them
alphabetically
    matches the order of labels in the label file.
    """
    image_files = [f for f in os.listdir(directory) if
f.endswith('.jpg')]
    image_files.sort()  # Sort files to ensure correct order with
labels

    images = []
    for filename in image_files:
        filepath = os.path.join(directory, filename)
        image = cv2.imread(filepath)
        if image is not None:
            image = cv2.resize(image, target_size)
            images.append(image)

    # Load labels from the .npy file
```

```
    labels = np.load(label_file)

    # Convert list of images to a numpy array
    images = np.array(images)

    return images, labels

from sklearn.model_selection import train_test_split
def save_datasets_memory_map(X_train, X_val, X_test, y_train, y_val, 
y_test, save_path):
    os.makedirs(save_path, exist_ok=True)
    np.save(os.path.join(save_path, 'X_train.npy'), X_train)
    np.save(os.path.join(save_path, 'X_val.npy'), X_val)
    np.save(os.path.join(save_path, 'X_test.npy'), X_test)
    np.save(os.path.join(save_path, 'y_train.npy'), y_train)
    np.save(os.path.join(save_path, 'y_val.npy'), y_val)
    np.save(os.path.join(save_path, 'y_test.npy'), y_test)

def split_data(images, labels, save_path, test_size=0.2, 
val_size=0.1):
    X_train, X_test, y_train, y_test = train_test_split(images, 
labels, test_size=test_size)
    X_train, X_val, y_train, y_val = train_test_split(X_train, 
y_train, test_size=val_size)
    # save datasets as memory maps
    save_datasets_memory_map(X_train, X_val, X_test, y_train, y_val, 
y_test, save_path)
    return None

def load_data_from_files(save_path):
    X_train = np.load(os.path.join(save_path, 'X_train.npy'), 
mmap_mode='r')
    X_test = np.load(os.path.join(save_path, 'X_test.npy'), 
mmap_mode='r')
    X_val = np.load(os.path.join(save_path, 'X_val.npy'), 
mmap_mode='r')
    y_train = np.load(os.path.join(save_path, 'y_train.npy'), 
mmap_mode='r')
    y_test = np.load(os.path.join(save_path, 'y_test.npy'), 
mmap_mode='r')
    y_val = np.load(os.path.join(save_path, 'y_val.npy'), 
mmap_mode='r')
    return X_train, X_test, X_val, y_train, y_test, y_val
```

Metrics

1. **Precision** measures the accuracy of positive predictions (i.e., the proportion of predicted positives that are actually true positives).

2. **Recall** measures the ability of the classifier to find all the positive samples (i.e., how well the model can detect actual positives from the dataset).
3. **F1 Score** is a way of combining the precision and recall of the model, and it is defined as the harmonic mean of the model's precision and recall.
4. **Confusion Matrix** is a table used to describe the performance of a classification model on a set of data for which the true values are known. It provides insights not just into the errors being made by a classifier but more importantly the types of errors.

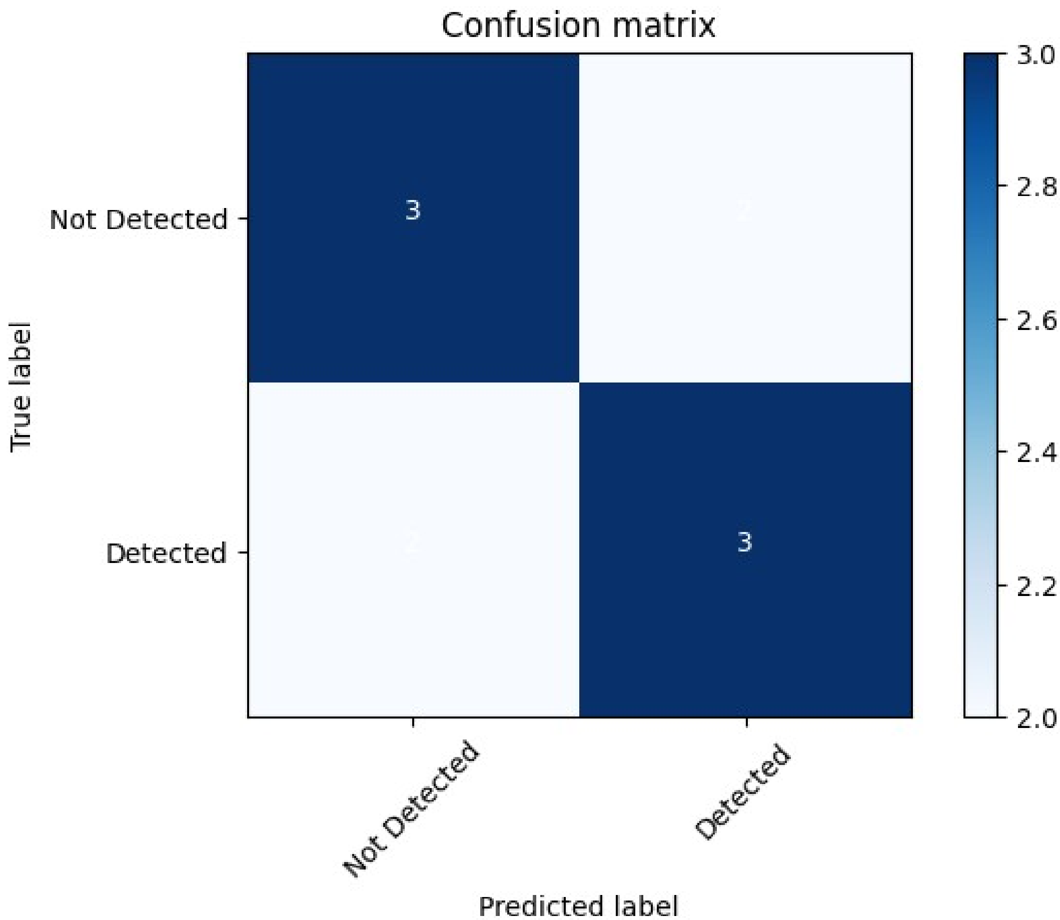
```
!pip install seaborn

Requirement already satisfied: seaborn in
/usr/local/lib/python3.10/dist-packages (0.13.1)
Requirement already satisfied: numpy!=1.24.0,>=1.20 in
/usr/local/lib/python3.10/dist-packages (from seaborn) (1.25.2)
Requirement already satisfied: pandas>=1.2 in
/usr/local/lib/python3.10/dist-packages (from seaborn) (2.0.3)
Requirement already satisfied: matplotlib!=3.6.1,>=3.4 in
/usr/local/lib/python3.10/dist-packages (from seaborn) (3.7.1)
Requirement already satisfied: contourpy>=1.0.1 in
/usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.4-
>seaborn) (1.2.1)
Requirement already satisfied: cycler>=0.10 in
/usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.4-
>seaborn) (0.12.1)
Requirement already satisfied: fonttools>=4.22.0 in
/usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.4-
>seaborn) (4.51.0)
Requirement already satisfied: kiwisolver>=1.0.1 in
/usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.4-
>seaborn) (1.4.5)
Requirement already satisfied: packaging>=20.0 in
/usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.4-
>seaborn) (24.0)
Requirement already satisfied: pillow>=6.2.0 in
/usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.4-
>seaborn) (9.4.0)
Requirement already satisfied: pyparsing>=2.3.1 in
/usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.4-
>seaborn) (3.1.2)
Requirement already satisfied: python-dateutil>=2.7 in
/usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.4-
>seaborn) (2.8.2)
Requirement already satisfied: pytz>=2020.1 in
/usr/local/lib/python3.10/dist-packages (from pandas>=1.2->seaborn)
(2023.4)
Requirement already satisfied: tzdata>=2022.1 in
/usr/local/lib/python3.10/dist-packages (from pandas>=1.2->seaborn)
(2024.1)
Requirement already satisfied: six>=1.5 in
```

```
/usr/local/lib/python3.10/dist-packages (from python-dateutil>=2.7-
>matplotlib!=3.6.1,>=3.4->seaborn) (1.16.0)
```

```python
import numpy as np
import seaborn as sns
import matplotlib.pyplot as plt

def calculate_precision_recall_f1(y_true, y_pred):
    # True positives, false positives, false negatives
    tp = np.sum((y_true == 1) & (y_pred == 1))
    fp = np.sum((y_true == 0) & (y_pred == 1))
    fn = np.sum((y_true == 1) & (y_pred == 0))

    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

    return precision, recall, f1

def confusion_matrix(y_true, y_pred):
    # Calculate confusion matrix components
    tp = np.sum((y_true == 1) & (y_pred == 1))
    tn = np.sum((y_true == 0) & (y_pred == 0))
    fp = np.sum((y_true == 0) & (y_pred == 1))
    fn = np.sum((y_true == 1) & (y_pred == 0))

    # Forming the confusion matrix
    cm = np.array([[tn, fp],
                   [fn, tp]])
    return cm

def plot_confusion_matrix(cm, classes=['Not Detected', 'Detected'],
                          title='Confusion matrix',
cmap=plt.cm.Blues):
    plt.imshow(cm, interpolation='nearest', cmap=cmap)
    plt.title(title)
    plt.colorbar()
    tick_marks = np.arange(len(classes))
    plt.xticks(tick_marks, classes, rotation=45)
    plt.yticks(tick_marks, classes)

    # Labeling the plot
    thresh = cm.max() / 2.
    for i, j in np.ndindex(cm.shape):
        plt.text(j, i, format(cm[i, j], 'd'),
                 horizontalalignment="center",
                 color="white" if cm[i, j] > thresh else "black")

    plt.tight_layout()
    plt.ylabel('True label')
```

```python
    plt.xlabel('Predicted label')
    plt.show()

import matplotlib.pyplot as plt

def plot_model_metrics(history):
    # Plot training & validation accuracy values
    plt.figure(figsize=(12, 5))

    plt.subplot(1, 2, 1)
    plt.plot(history.history['accuracy'])
    plt.plot(history.history['val_accuracy'])
    plt.title('Model accuracy')
    plt.ylabel('Accuracy')
    plt.xlabel('Epoch')
    plt.legend(['Train', 'Validation'], loc='upper left')

    # Plot training & validation loss values
    plt.subplot(1, 2, 2)
    plt.plot(history.history['loss'])
    plt.plot(history.history['val_loss'])
    plt.title('Model loss')
    plt.ylabel('Loss')
    plt.xlabel('Epoch')
    plt.legend(['Train', 'Validation'], loc='upper left')

    plt.tight_layout()
    plt.show()

# Example usage
# Sample labels (0: not detected, 1: detected)
y_true = np.array([1, 0, 1, 1, 0, 0, 1, 0, 0, 1])
y_pred = np.array([1, 0, 0, 1, 0, 1, 1, 1, 0, 0])

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.6
Recall: 0.6
F1 Score: 0.6
```



Load the data for all the datasets

```
# Load images and labels - normal dataset
directory = 'modified_datasets/normal'
label_file = 'modified_datasets/normal/labels.npy'
images, labels = load_images_from_directory(directory, label_file)
save_path = 'modified_datasets/normal'

# Split data
split_data(images, labels, save_path)
# Load the data
X_train, X_test, X_val, y_train, y_test, y_val =
load_data_from_files(save_path)

# Load images and labels - eyebrows
directory = 'modified_datasets/masked_eyebrows'
label_file = 'modified_datasets/masked_eyebrows/labels.npy'
images, labels = load_images_from_directory(directory, label_file)
save_path = 'modified_datasets/masked_eyebrows'
```

```python
# Split data
split_data(images, labels, save_path)
# Load the data
X_train_brows, X_test_brows, X_val_brows, y_train_brows, y_test_brows,
y_val_brows = load_data_from_files(save_path)

# Load images and labels - eyes
directory = 'modified_datasets/masked_eyes'
label_file = 'modified_datasets/masked_eyes/labels.npy'
images, labels = load_images_from_directory(directory, label_file)
save_path = 'modified_datasets/masked_eyes'

# Split data
split_data(images, labels, save_path)
# Load the data
X_train_eyes, X_test_eyes, X_val_eyes, y_train_eyes, y_test_eyes,
y_val_eyes = load_data_from_files(save_path)

# Load images and labels - nose
directory = 'modified_datasets/masked_nose'
label_file = 'modified_datasets/masked_nose/labels.npy'
images, labels = load_images_from_directory(directory, label_file)
save_path = 'modified_datasets/masked_nose'

# Split data
split_data(images, labels, save_path)
# Load the data
X_train_nose, X_test_nose, X_val_nose, y_train_nose, y_test_nose,
y_val_nose = load_data_from_files(save_path)

# Load images and labels - mouth
directory = 'modified_datasets/masked_mouth'
label_file = 'modified_datasets/masked_mouth/labels.npy'
images, labels = load_images_from_directory(directory, label_file)
save_path = 'modified_datasets/masked_mouth'

# Split data
split_data(images, labels, save_path)
# Load the data
X_train_mouth, X_test_mouth, X_val_mouth, y_train_mouth, y_test_mouth,
y_val_noise = load_data_from_files(save_path)
```

Let's do this from scratch - one final time!!

Original Model

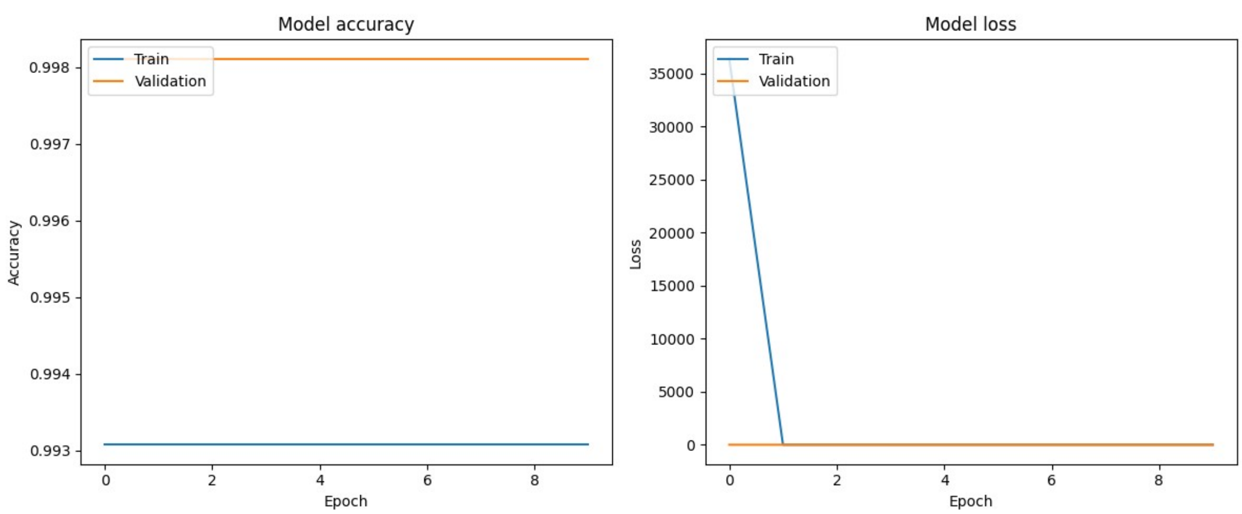
```python
from keras.backend import clear_session
# Original model
```

```python
def build_model():
  # Load VGGFace model
  base_model = VGGFace(model='vgg16', include_top=False,
input_shape=(224, 224, 3), pooling='avg')

  # Add new classifier layers
  flat1 = Flatten()(base_model.output)
  output = Dense(1, activation='sigmoid')(flat1)
  final_model = Model(inputs=base_model.inputs, outputs=output)

  # Compile the model
  final_model.compile(optimizer='adam', loss='binary_crossentropy',
metrics=['accuracy'])

  # Display model summary
  # final_model.summary()

  return final_model


# Reset the Keras session
clear_session()
# build the model
face_model = build_model()

face_model.summary()
```

```
Model: "model"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 input_1 (InputLayer)        [(None, 224, 224, 3)]     0

 conv1_1 (Conv2D)            (None, 224, 224, 64)      1792

 conv1_2 (Conv2D)            (None, 224, 224, 64)      36928

 pool1 (MaxPooling2D)        (None, 112, 112, 64)      0

 conv2_1 (Conv2D)            (None, 112, 112, 128)     73856

 conv2_2 (Conv2D)            (None, 112, 112, 128)     147584

 pool2 (MaxPooling2D)        (None, 56, 56, 128)       0

 conv3_1 (Conv2D)            (None, 56, 56, 256)       295168

 conv3_2 (Conv2D)            (None, 56, 56, 256)       590080

 conv3_3 (Conv2D)            (None, 56, 56, 256)       590080
```

```
 pool3 (MaxPooling2D)        (None, 28, 28, 256)       0

 conv4_1 (Conv2D)            (None, 28, 28, 512)       1180160

 conv4_2 (Conv2D)            (None, 28, 28, 512)       2359808

 conv4_3 (Conv2D)            (None, 28, 28, 512)       2359808

 pool4 (MaxPooling2D)        (None, 14, 14, 512)       0

 conv5_1 (Conv2D)            (None, 14, 14, 512)       2359808

 conv5_2 (Conv2D)            (None, 14, 14, 512)       2359808

 conv5_3 (Conv2D)            (None, 14, 14, 512)       2359808

 pool5 (MaxPooling2D)        (None, 7, 7, 512)         0

 global_average_pooling2d (G  (None, 512)              0
 lobalAveragePooling2D)

 flatten (Flatten)           (None, 512)               0

 dense (Dense)               (None, 1)                 513

=================================================================
Total params: 14,715,201
Trainable params: 14,715,201
Non-trainable params: 0
_________________________________________________________________

# Training the model on good data
from tensorflow.keras.callbacks import ModelCheckpoint, EarlyStopping
# Set up callbacks
checkpoint = ModelCheckpoint('best_model.h5', save_best_only=True,
monitor='val_loss', mode='min')
early_stop = EarlyStopping(monitor='val_loss', patience=10,
restore_best_weights=True)
history = face_model.fit(X_train, y_train, epochs=10, batch_size=20,
                         validation_data=(X_val, y_val),
                         callbacks=[checkpoint, early_stop])

Epoch 1/10
477/477 [==============================] - 74s 155ms/step - loss:
36393.7578 - accuracy: 0.9931 - val_loss: 0.5179 - val_accuracy:
0.9981
Epoch 2/10
477/477 [==============================] - 69s 144ms/step - loss:
0.4227 - accuracy: 0.9931 - val_loss: 0.3423 - val_accuracy: 0.9981
```

```
Epoch 3/10
477/477 [==============================] - 69s 144ms/step - loss:
0.2957 - accuracy: 0.9931 - val_loss: 0.2454 - val_accuracy: 0.9981
Epoch 4/10
477/477 [==============================] - 69s 144ms/step - loss:
0.2195 - accuracy: 0.9931 - val_loss: 0.1829 - val_accuracy: 0.9981
Epoch 5/10
477/477 [==============================] - 69s 145ms/step - loss:
0.1693 - accuracy: 0.9931 - val_loss: 0.1403 - val_accuracy: 0.9981
Epoch 6/10
477/477 [==============================] - 69s 145ms/step - loss:
0.1347 - accuracy: 0.9931 - val_loss: 0.1100 - val_accuracy: 0.9981
Epoch 7/10
477/477 [==============================] - 69s 145ms/step - loss:
0.1101 - accuracy: 0.9931 - val_loss: 0.0879 - val_accuracy: 0.9981
Epoch 8/10
477/477 [==============================] - 69s 145ms/step - loss:
0.0922 - accuracy: 0.9931 - val_loss: 0.0715 - val_accuracy: 0.9981
Epoch 9/10
477/477 [==============================] - 69s 145ms/step - loss:
0.0790 - accuracy: 0.9931 - val_loss: 0.0590 - val_accuracy: 0.9981
Epoch 10/10
477/477 [==============================] - 69s 145ms/step - loss:
0.0692 - accuracy: 0.9931 - val_loss: 0.0495 - val_accuracy: 0.9981

# Plot the metrics
plot_model_metrics(history)
```



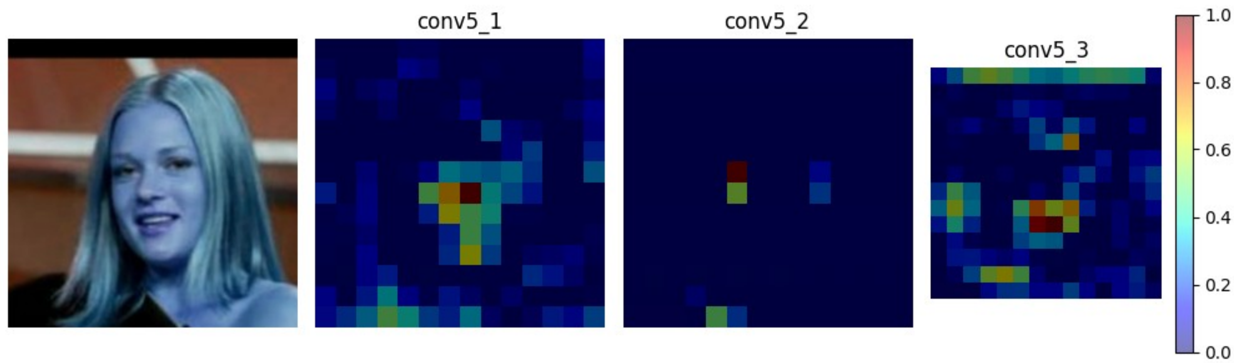
Activation Maps

```
# Activation Heat maps
import matplotlib.pyplot as plt
```

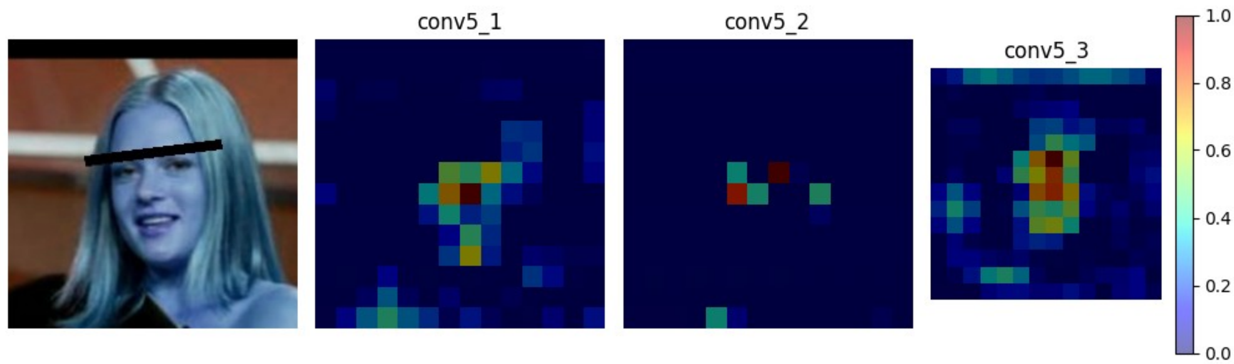
```
import numpy as np
import tensorflow as tf
from tensorflow.keras.applications.vgg16 import preprocess_input
from tensorflow.keras.models import Model
import cv2

# Function to generate Grad-CAM heatmap
def make_gradcam_heatmap(img_array, model, last_conv_layer_name,
classifier_layer_names):
    # Model with both the last CNN layer and classifier layers output
    grad_model = Model([model.inputs],
[model.get_layer(last_conv_layer_name).output] +
[model.get_layer(name).output for name in classifier_layer_names])

    # Record operations for automatic differentiation
    with tf.GradientTape() as tape:
        # Forward pass
        last_conv_layer_output, preds = grad_model(img_array)
        top_pred_index = tf.argmax(preds[0])
        top_class_channel = preds[:, top_pred_index]

    # Gradient of top predicted class with respect to the output
feature map of last conv layer
    grads = tape.gradient(top_class_channel, last_conv_layer_output)

    # This vector contains importance weights of each channel in
feature map
    pooled_grads = tf.reduce_mean(grads, axis=(0, 1, 2))

    # Weight the channels by their importance to the top predicted
class
    last_conv_layer_output = last_conv_layer_output[0]
    heatmap = last_conv_layer_output @ pooled_grads[..., tf.newaxis]
    heatmap = tf.squeeze(heatmap)

    # Normalize the heatmap
    heatmap = tf.maximum(heatmap, 0) / tf.math.reduce_max(heatmap)
    return heatmap.numpy()

# Function to plot the original image and heatmaps
def plot_heatmaps(img_path, model, layers, classifier_layer_names):
    img = cv2.imread(img_path)
    img = cv2.cvtColor(img, cv2.COLOR_BGR2RGB)
    img_array = preprocess_input(img)  # Add your preprocessing logic
here
    img_array = np.expand_dims(img_array, axis=0)  # Add batch
dimension

    # Plot original image
    plt.figure(figsize=(10, 3))
```

```
    plt.subplot(1, len(layers) + 1, 1)
    plt.imshow(img)
    plt.axis('off')

    # Generate and plot heatmaps for each layer
    for i, layer in enumerate(layers, start=2):
        heatmap = make_gradcam_heatmap(img_array, model, layer,
classifier_layer_names)
        plt.subplot(1, len(layers) + 1, i)
        plt.imshow(img)
        plt.imshow(heatmap, cmap='jet', alpha=0.5)  # Overlay heatmap
        plt.title(layer)
        plt.axis('off')

    plt.tight_layout()
    plt.colorbar()
    plt.show()

# List of layers to check
later_layers = ['conv5_1', 'conv5_2', 'conv5_3']
early_layers = ['conv1_1', 'conv1_2', 'conv2_1', 'conv2_2', 'conv3_1',
'conv3_2']
middle_layers = ['conv4_1', 'conv4_2', 'conv4_3']
classifier_layer_names = ["dense"]  # Names of classifier layers in
your model

# Define paths to your datasets
image_paths = {
    'normal': 'modified_datasets/normal/AJ_Cook_0001.jpg',
    'eyebrows': 'modified_datasets/masked_eyebrows/AJ_Cook_0001.jpg',
    'eyes': 'modified_datasets/masked_eyes/AJ_Cook_0001.jpg',
    'nose': 'modified_datasets/masked_nose/AJ_Cook_0001.jpg',
    'mouth': 'modified_datasets/masked_mouth/AJ_Cook_0001.jpg'
}

# Loop over the datasets and plot the heatmaps
for feature, img_path in image_paths.items():
    print(f"Analyzing feature: {feature}")
    plot_heatmaps(img_path, face_model, later_layers,
classifier_layer_names)
```

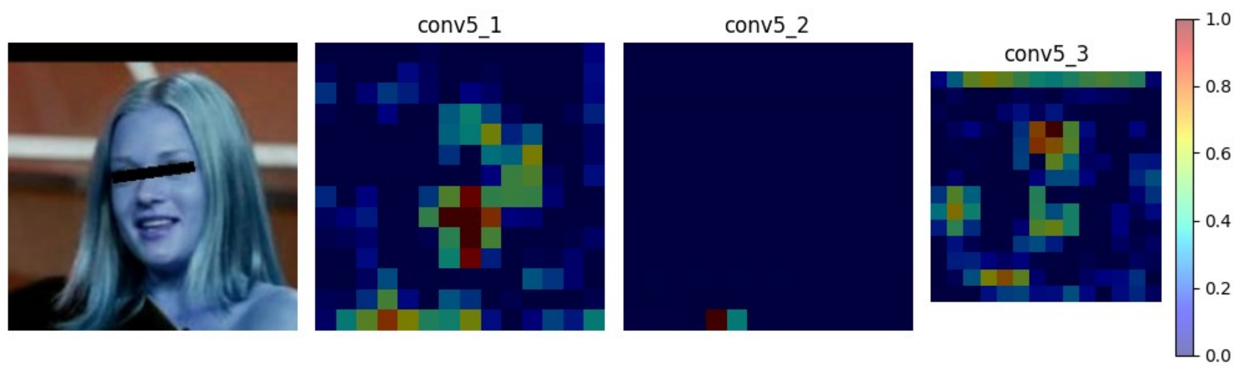
```
Analyzing feature: normal
```



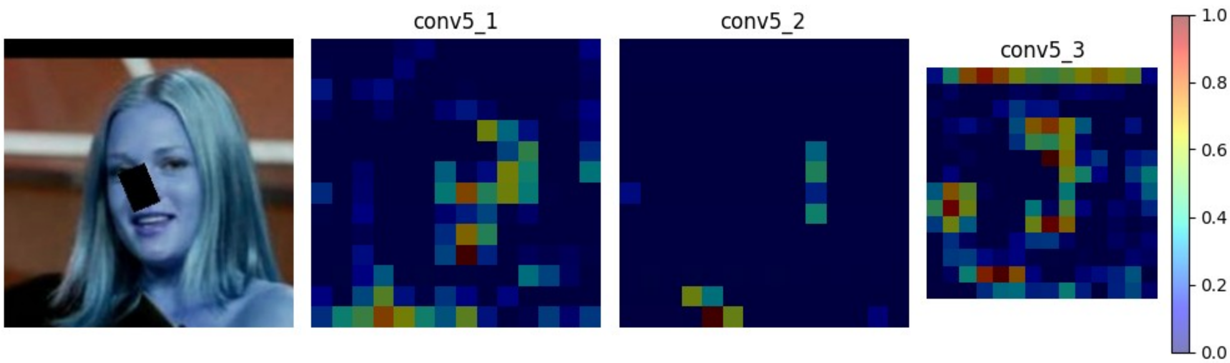

```
Analyzing feature: eyebrows
```



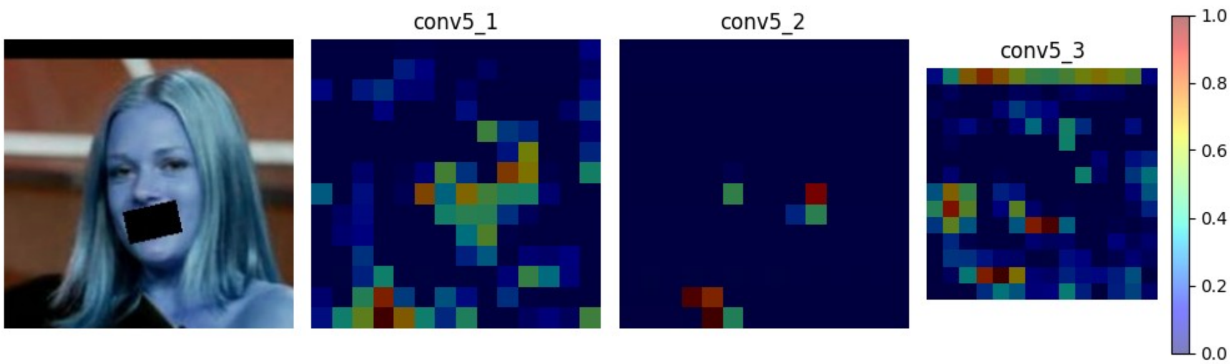

```
Analyzing feature: eyes
```




```
Analyzing feature: nose
```

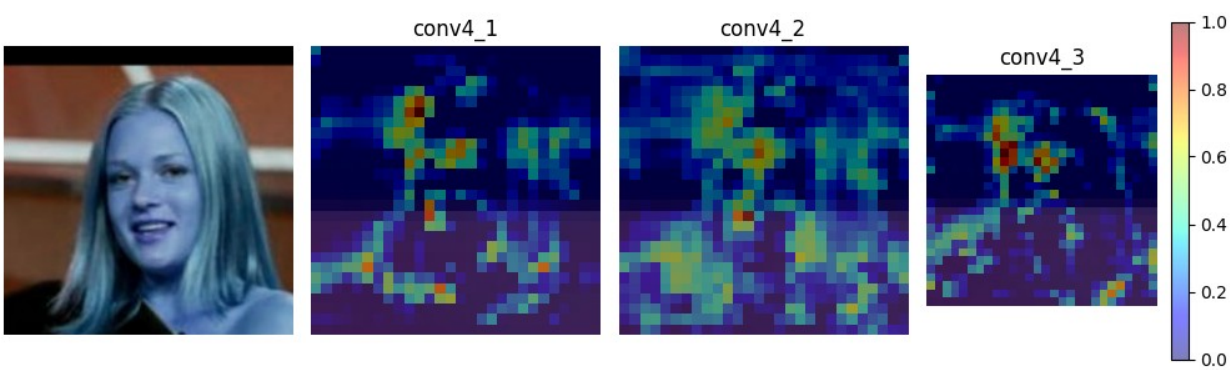



```
Analyzing feature: mouth
```

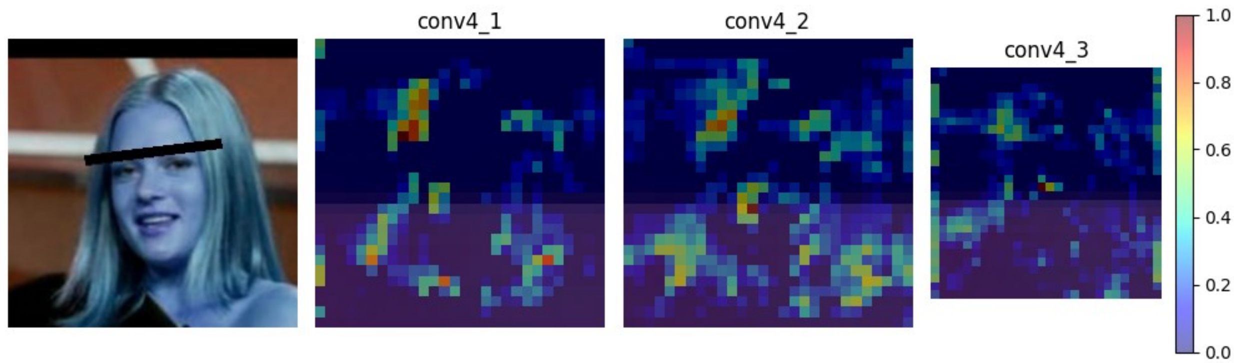



```python
# Loop over the datasets and plot the heatmaps
for feature, img_path in image_paths.items():
    print(f"Analyzing feature: {feature}")
    plot_heatmaps(img_path, face_model, middle_layers,
classifier_layer_names)
```

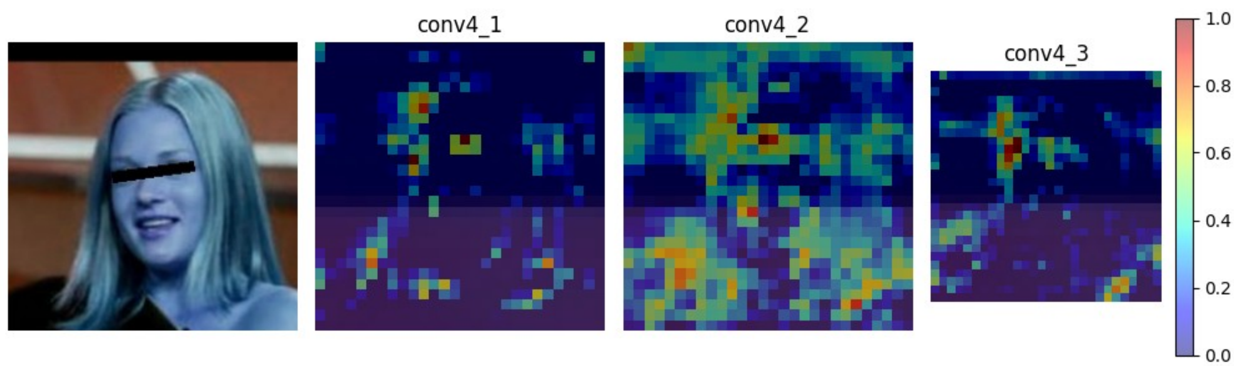
```
Analyzing feature: normal
```



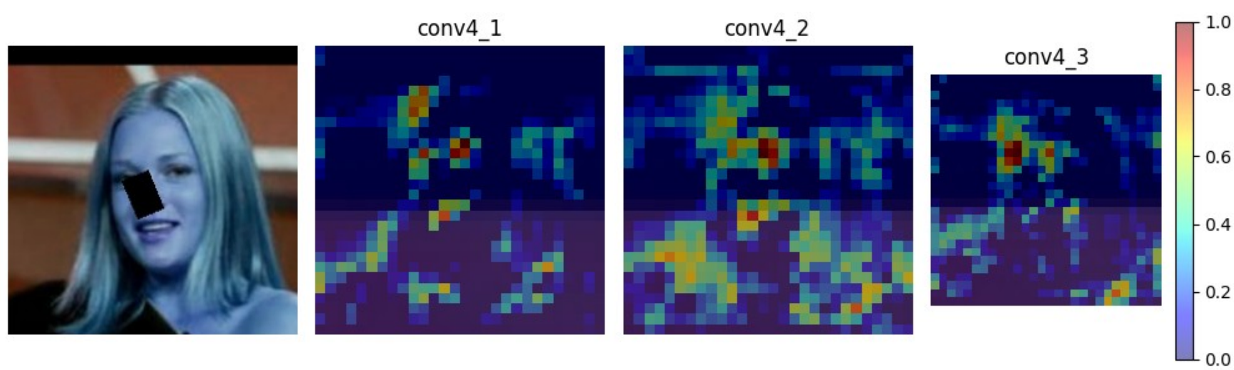

```
Analyzing feature: eyebrows
```



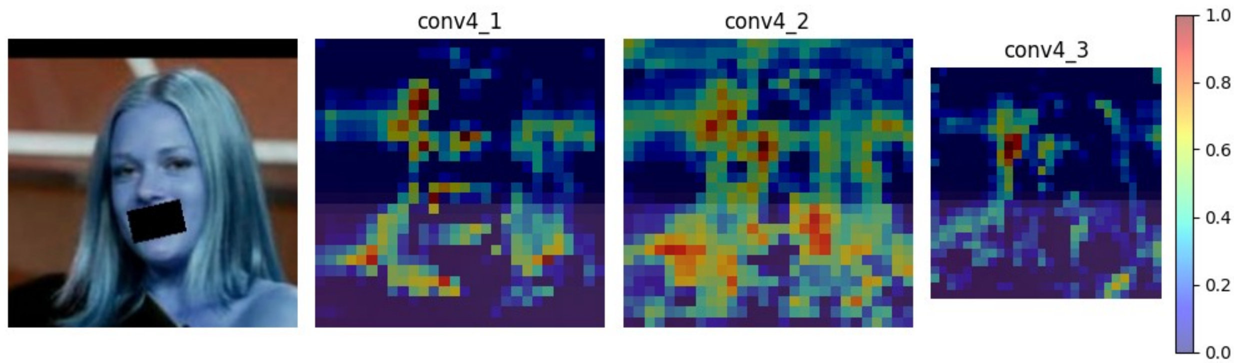

```
Analyzing feature: eyes
```




```
Analyzing feature: nose
```



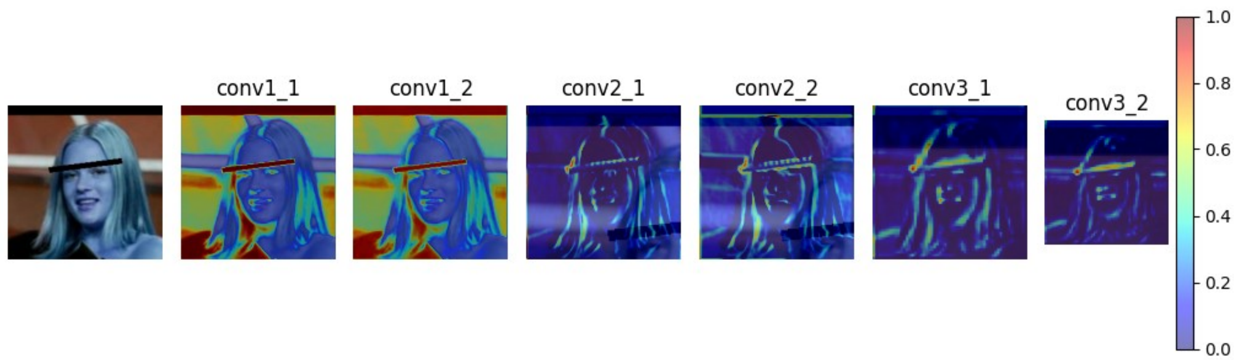

```
Analyzing feature: mouth
```



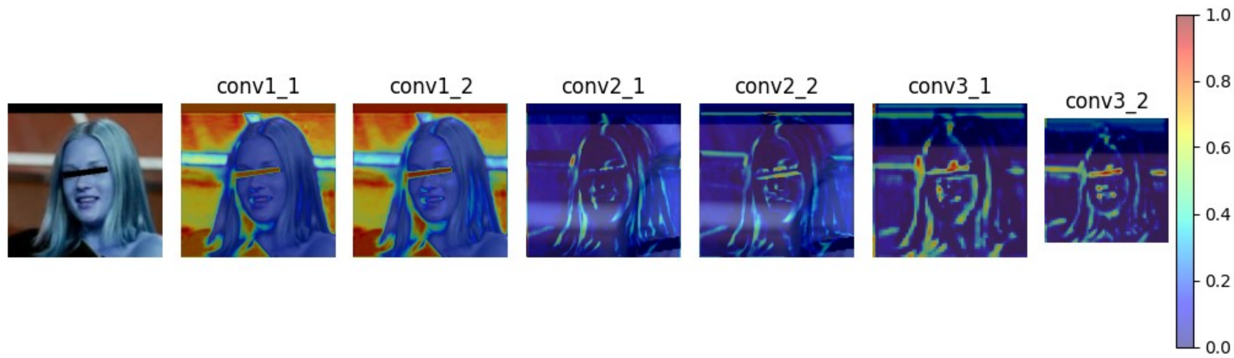

```
# Loop over the datasets and plot the heatmaps
for feature, img_path in image_paths.items():
    print(f"Analyzing feature: {feature}")
    plot_heatmaps(img_path, face_model, early_layers,
classifier_layer_names)
```

```
Analyzing feature: normal
```

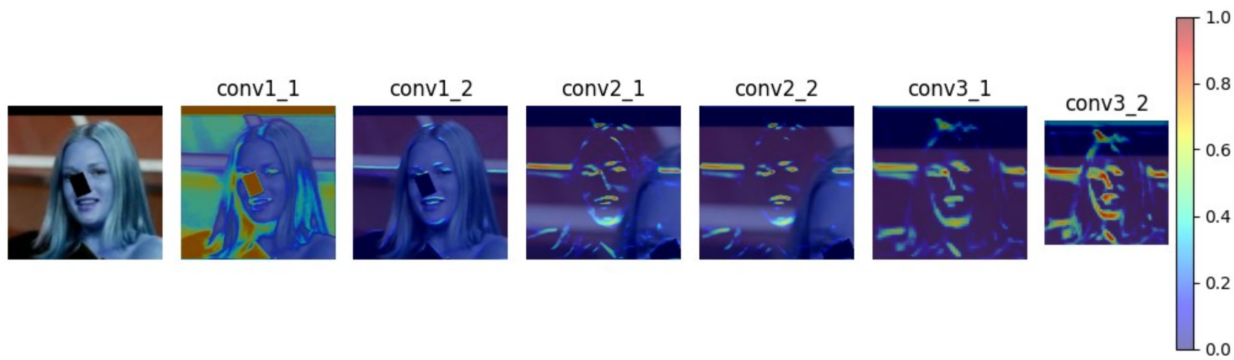

```
Analyzing feature: eyebrows
```



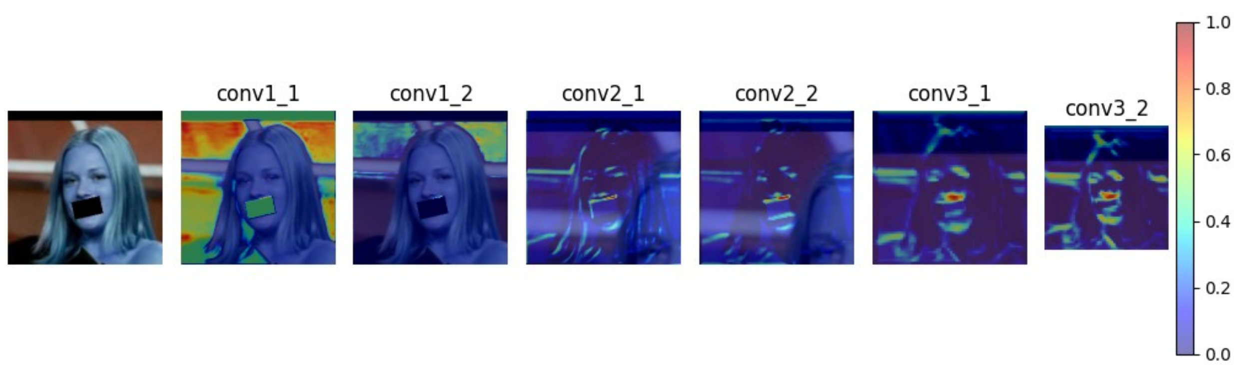

```
Analyzing feature: eyes
```




```
Analyzing feature: nose
```




```
Analyzing feature: mouth
```



Performance of Original Model

```
# orignal model's performance on normal data
# Load the test dataset
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
```

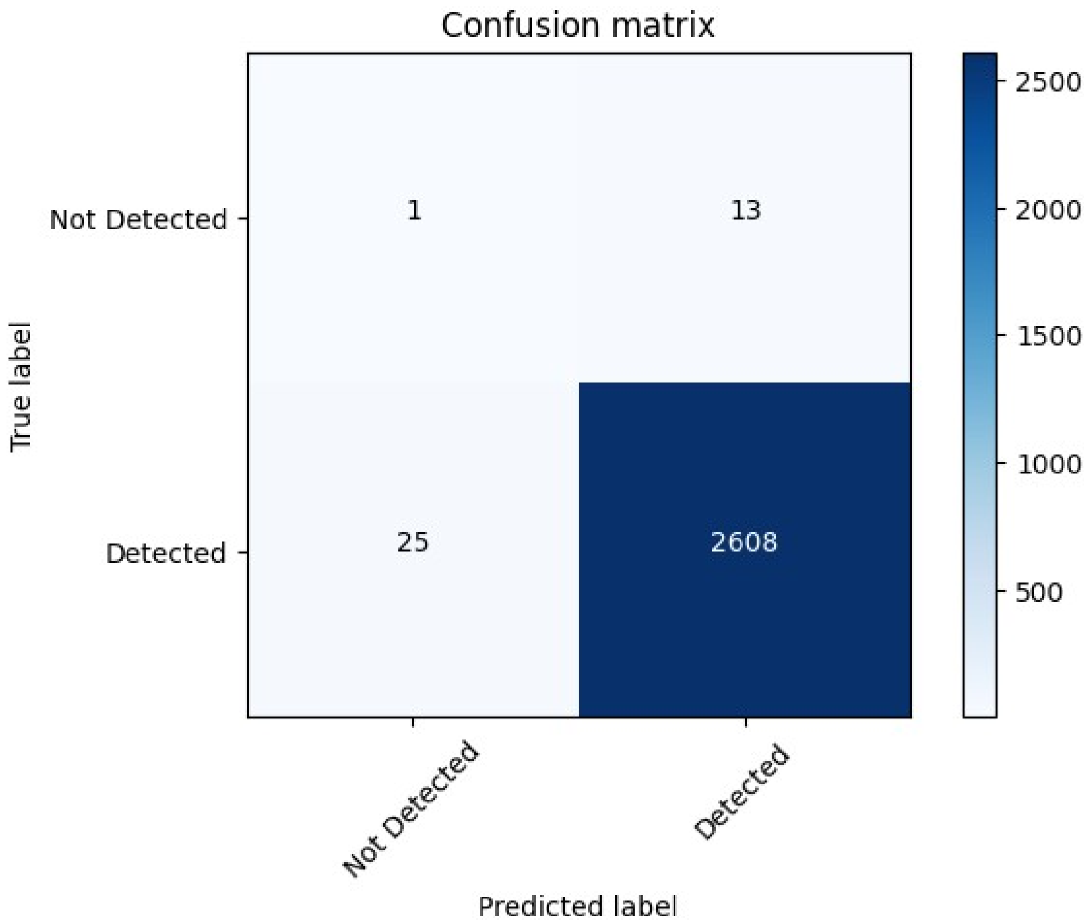
```
threshold = 0.5

num_runs = 5
total_accuracy = 0

for run in range(num_runs):
  clear_session()
  face_model = build_model()

  predictions = face_model.predict(test_images)
  binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

  # Calculate accuracy
  num_correct = 0
  total_images = len(test_images)
  for i in range(total_images):
      predicted_class = binary_predictions[i]
      true_class = test_labels[i]
      if predicted_class == true_class:
          num_correct += 1

  accuracy = num_correct / total_images
  total_accuracy += accuracy
  print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")
# Calculate the average accuracy over all runs
avg_accuracy = total_accuracy / num_runs
print(f"Average Accuracy over {num_runs} runs: {avg_accuracy *
100:.2f}%")




# # Make predictions using the model
# # predictions = final_model.predict(test_images)
# predictions = face_model.predict(test_images)
# binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

# # Calculate accuracy
# num_correct = 0
# total_images = len(test_images)

# for i in range(total_images):
#     predicted_class = binary_predictions[i]
#     true_class = test_labels[i]
#     if predicted_class == true_class:
#         num_correct += 1
```

```
# accuracy = num_correct / total_images
# print("Original model accuracy with normal data", accuracy)
```

```
83/83 [==============================] - 8s 90ms/step
Run 1: Accuracy = 23.04%
83/83 [==============================] - 8s 91ms/step
Run 2: Accuracy = 50.40%
83/83 [==============================] - 8s 91ms/step
Run 3: Accuracy = 96.49%
83/83 [==============================] - 8s 92ms/step
Run 4: Accuracy = 96.41%
83/83 [==============================] - 8s 93ms/step
Run 5: Accuracy = 98.56%
Average Accuracy over 5 runs: 72.98%
```

```
# performace on normal data
y_true = test_labels
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9950400610454025
Recall: 0.9905051272312951
F1 Score: 0.9927674153026266
```



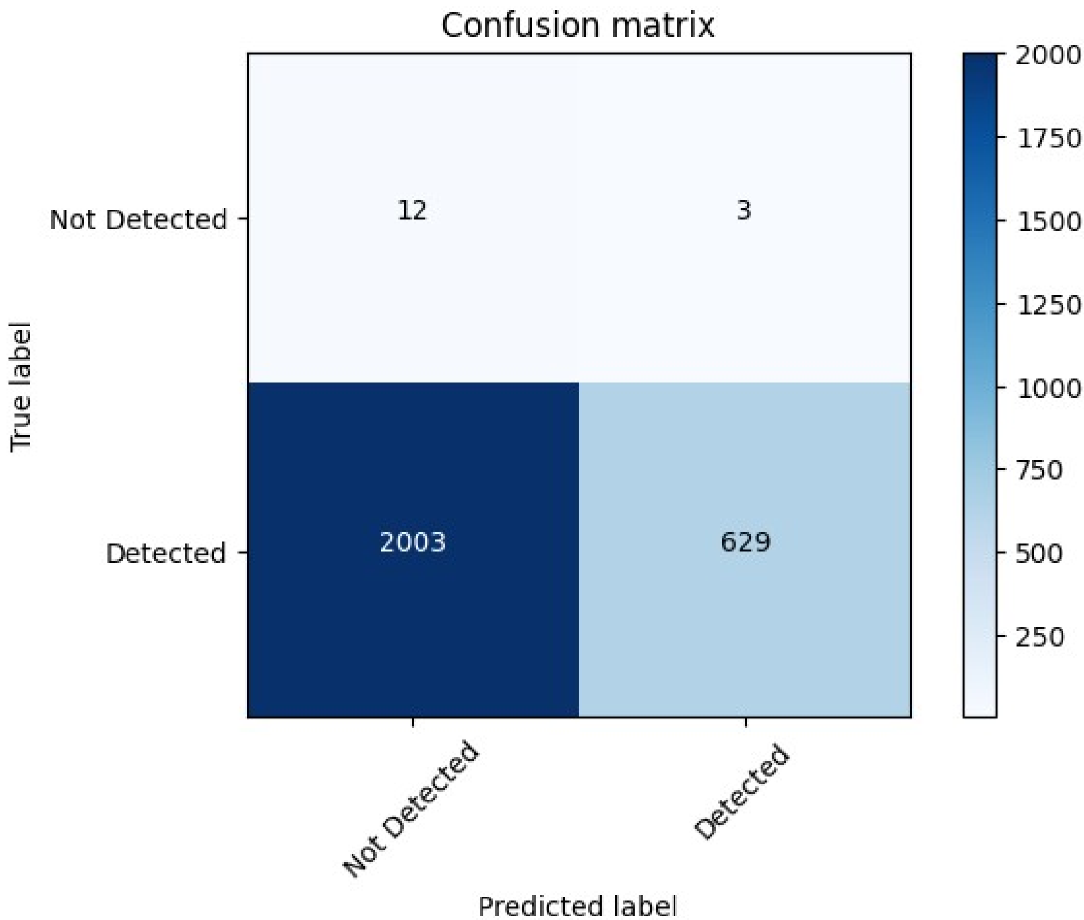

```
test_images = X_test_brows # Load your test images here
test_labels = y_test_brows # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

num_runs = 5
total_accuracy = 0

for run in range(num_runs):
  clear_session()
  face_model = build_model()

  predictions = face_model.predict(test_images)
  binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

  # Calculate accuracy
  num_correct = 0
  total_images = len(test_images)
  for i in range(total_images):
```

```
        predicted_class = binary_predictions[i]
        true_class = test_labels[i]
        if predicted_class == true_class:
            num_correct += 1

    accuracy = num_correct / total_images
    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")
# Calculate the average accuracy over all runs
avg_accuracy = total_accuracy / num_runs
print(f"Average Accuracy over {num_runs} runs: {avg_accuracy *
100:.2f}%")
```

```
83/83 [==============================] - 8s 92ms/step
Run 1: Accuracy = 97.24%
83/83 [==============================] - 8s 92ms/step
Run 2: Accuracy = 86.89%
83/83 [==============================] - 8s 93ms/step
Run 3: Accuracy = 3.70%
83/83 [==============================] - 8s 93ms/step
Run 4: Accuracy = 95.92%
83/83 [==============================] - 8s 93ms/step
Run 5: Accuracy = 24.22%
Average Accuracy over 5 runs: 61.59%
```

```
# performace on masked data
y_true = test_labels
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.995253164556962
Recall: 0.23898176291793313
F1 Score: 0.3854166666666667
```



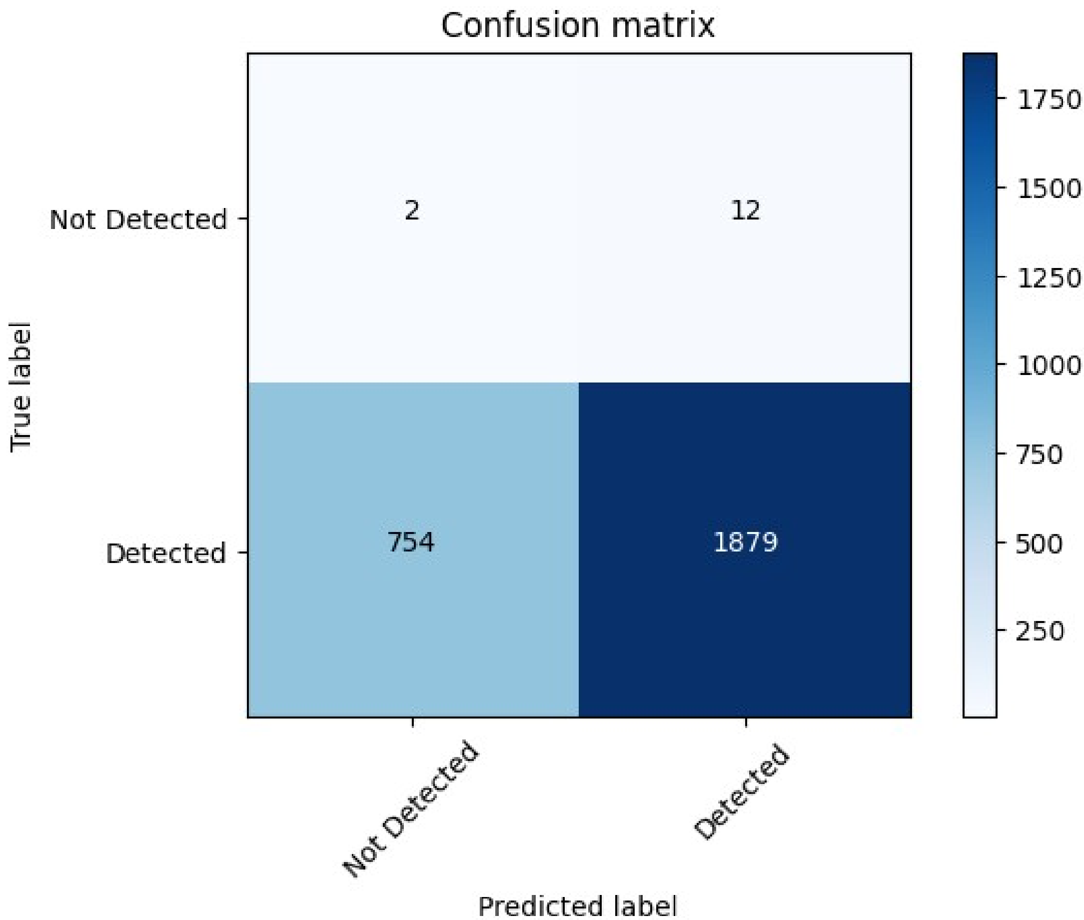

```
test_images = X_test_eyes # Load your test images here
test_labels = y_test_eyes # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

num_runs = 5
total_accuracy = 0

for run in range(num_runs):
  clear_session()
  face_model = build_model()

  predictions = face_model.predict(test_images)
  binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

  # Calculate accuracy
  num_correct = 0
  total_images = len(test_images)
  for i in range(total_images):
```

```
        predicted_class = binary_predictions[i]
        true_class = test_labels[i]
        if predicted_class == true_class:
            num_correct += 1

    accuracy = num_correct / total_images
    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")
# Calculate the average accuracy over all runs
avg_accuracy = total_accuracy / num_runs
print(f"Average Accuracy over {num_runs} runs: {avg_accuracy *
100:.2f}%")
```

```
83/83 [==============================] - 8s 90ms/step
Run 1: Accuracy = 83.83%
83/83 [==============================] - 8s 91ms/step
Run 2: Accuracy = 25.39%
83/83 [==============================] - 8s 93ms/step
Run 3: Accuracy = 61.09%
83/83 [==============================] - 8s 94ms/step
Run 4: Accuracy = 29.88%
83/83 [==============================] - 8s 95ms/step
Run 5: Accuracy = 71.06%
Average Accuracy over 5 runs: 54.25%
```

```
# performace on masked eyes
y_true = test_labels
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9936541512427287
Recall: 0.7136346372958602
F1 Score: 0.8306808134394341
```



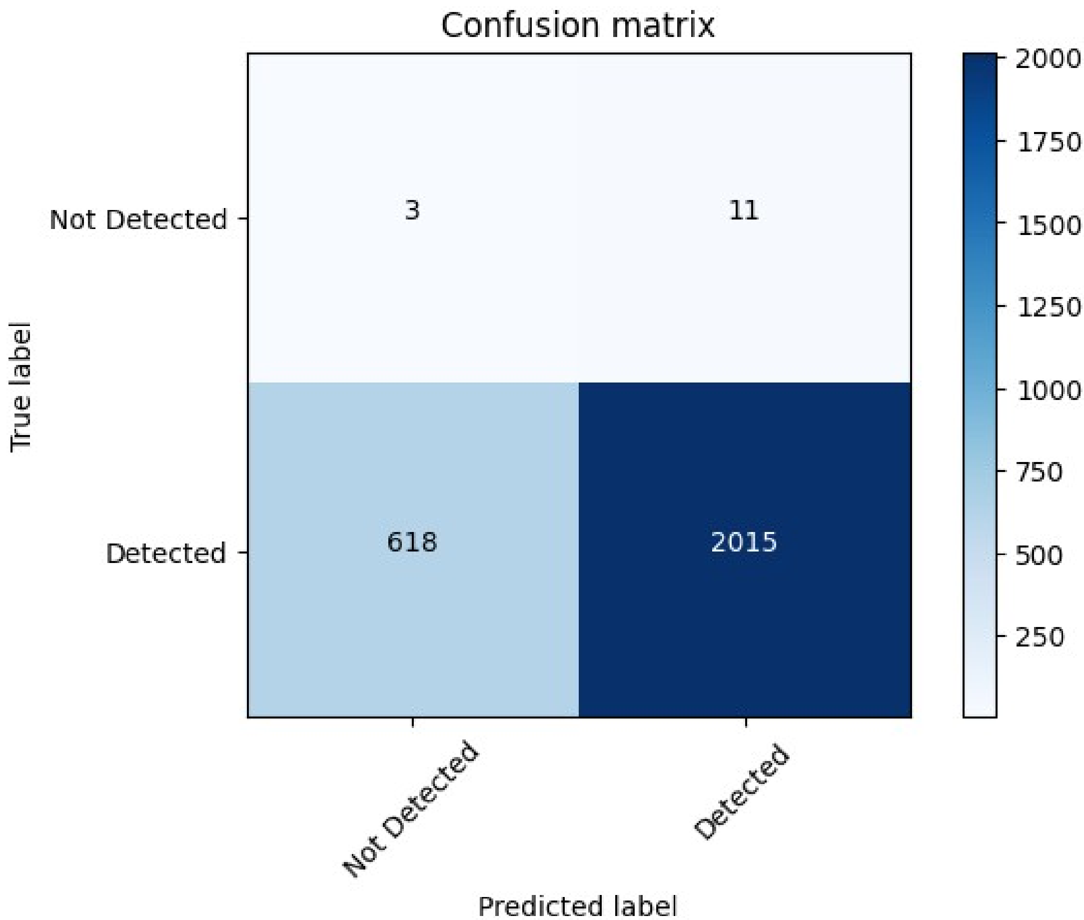

```
test_images = X_test_nose # Load your test images here
test_labels = y_test_nose # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

num_runs = 5
total_accuracy = 0

for run in range(num_runs):
  clear_session()
  face_model = build_model()

  predictions = face_model.predict(test_images)
  binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

  # Calculate accuracy
  num_correct = 0
  total_images = len(test_images)
  for i in range(total_images):
```

```
        predicted_class = binary_predictions[i]
        true_class = test_labels[i]
        if predicted_class == true_class:
            num_correct += 1

    accuracy = num_correct / total_images
    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")
# Calculate the average accuracy over all runs
avg_accuracy = total_accuracy / num_runs
print(f"Average Accuracy over {num_runs} runs: {avg_accuracy *
100:.2f}%")
```

```
83/83 [==============================] - 8s 94ms/step
Run 1: Accuracy = 75.29%
83/83 [==============================] - 8s 94ms/step
Run 2: Accuracy = 38.87%
83/83 [==============================] - 8s 94ms/step
Run 3: Accuracy = 77.22%
83/83 [==============================] - 8s 95ms/step
Run 4: Accuracy = 77.18%
83/83 [==============================] - 8s 96ms/step
Run 5: Accuracy = 76.24%
Average Accuracy over 5 runs: 68.96%
```

```
# performace on masked nose
y_true = test_labels
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9945705824284304
Recall: 0.7652867451576149
F1 Score: 0.8649924876582958
```

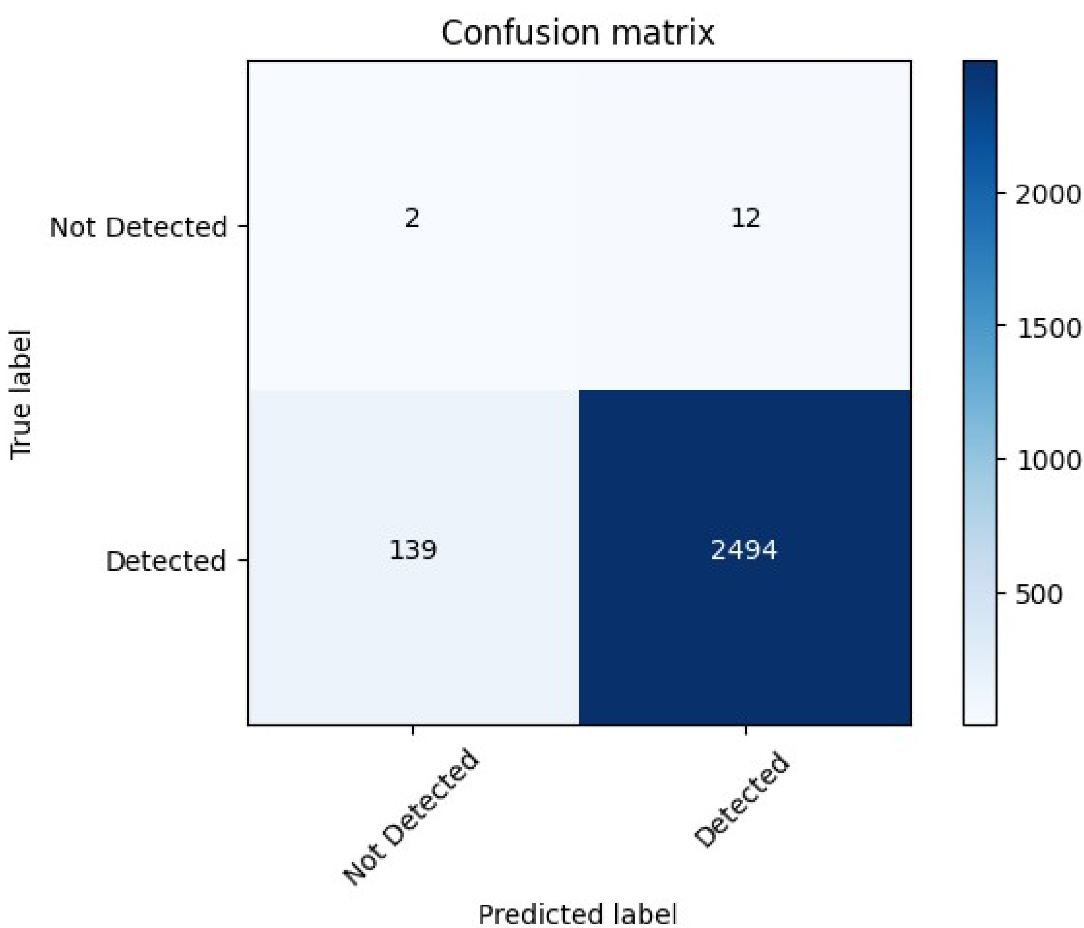



```
# clear_session()
# face_model = build_model()
# # orignal model's performance on normal data
# # Load the test dataset
# test_images = X_test_mouth # Load your test images here
# test_labels = y_test_mouth # Load your test labels here

# # Define a threshold for classifying as face detected
# threshold = 0.5

# # Make predictions using the model
# # predictions = final_model.predict(test_images)
# predictions = face_model.predict(test_images)
# binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

# # Calculate accuracy
# num_correct = 0
# total_images = len(test_images)

# for i in range(total_images):
```

```
#     predicted_class = binary_predictions[i]
#     true_class = test_labels[i]
#     if predicted_class == true_class:
#         num_correct += 1

# accuracy = num_correct / total_images
# print("Original model accuracy with masked mouth data", accuracy)

test_images = X_test_nose # Load your test images here
test_labels = y_test_nose # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

num_runs = 5
total_accuracy = 0

for run in range(num_runs):
  clear_session()
  face_model = build_model()

  predictions = face_model.predict(test_images)
  binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

  # Calculate accuracy
  num_correct = 0
  total_images = len(test_images)
  for i in range(total_images):
      predicted_class = binary_predictions[i]
      true_class = test_labels[i]
      if predicted_class == true_class:
          num_correct += 1

  accuracy = num_correct / total_images
  total_accuracy += accuracy
  print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")
# Calculate the average accuracy over all runs
avg_accuracy = total_accuracy / num_runs
print(f"Average Accuracy over {num_runs} runs: {avg_accuracy *
100:.2f}%")
```

```
83/83 [==============================] - 8s 93ms/step
Run 1: Accuracy = 99.43%
83/83 [==============================] - 8s 94ms/step
Run 2: Accuracy = 0.72%
83/83 [==============================] - 8s 95ms/step
Run 3: Accuracy = 56.37%
83/83 [==============================] - 8s 96ms/step
Run 4: Accuracy = 0.60%
```

```
83/83 [==============================] - 8s 98ms/step
Run 5: Accuracy = 94.30%
Average Accuracy over 5 runs: 50.28%

# performace on masked_mouth
y_true = test_labels
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)

Precision: 0.9952114924181963
Recall: 0.9472085074060007
F1 Score: 0.9706168515275345
```



Neurological Deficits

Prepare Dataste for Training for Deficit Models

```
datasets = [(X_train_eyes, y_train_eyes), (X_train_nose,
y_train_nose), (X_train_brows, y_train_brows), (X_train_mouth,
y_train_mouth)]
X_train_combined = np.vstack([data[0] for data in datasets])
y_train_combined = np.hstack([data[1] for data in datasets])

# Shuffle the combined dataset
indices = np.arange(len(y_train))
np.random.shuffle(indices)
X_train_combined = X_train_combined[indices]
y_train_combined = y_train_combined[indices]

# Optionally limit the dataset to the first 10000 samples
X_train_deficit = X_train_combined[:10000]
y_train_deficit = y_train_combined[:10000]
```

Approach 1: Feature Ablation

```
# Neurological deficit  - ablate conv4_3 to conv5_3

from keras.models import Model
from keras_vggface.vggface import VGGFace
from tensorflow.keras.layers import Flatten, Dense, Lambda
import tensorflow as tf

def build_model_with_ablation(ablation_layers):
    # Load VGGFace model
    base_model = VGGFace(model='vgg16', include_top=False,
input_shape=(224, 224, 3), pooling='avg')

    # Function to zero-out activations
    def ablate_features(x, layers_to_ablate):
        for layer_name in layers_to_ablate:
            if base_model.get_layer(layer_name) == x.name:
                return tf.zeros_like(x)
        return x

    # Add ablation layers after convolutional layers
    x = base_model.input
    for layer in base_model.layers:
        layer_output = layer(x)
        # Apply ablation if the layer is in the ablation list
        x = Lambda(lambda x: ablate_features(x, ablation_layers),
name=f'ablated_{layer.name}')(layer_output)
```

```
    # Add new classifier layers
    flat1 = Flatten()(x)
    output = Dense(1, activation='sigmoid')(flat1)

    # Define the new model
    model_with_ablation = Model(inputs=base_model.input,
outputs=output)

    # Compile the model
    model_with_ablation.compile(optimizer='adam',
loss='binary_crossentropy', metrics=['accuracy'])

    return model_with_ablation

clear_session()
face_model = build_model()
# Specify the layers to be ablated based on Grad-CAM results
layers_to_ablate = ['conv4_3', 'conv5_1', 'conv5_2', 'conv5_3']

# Build the model with feature ablation
face_model_with_ablation = build_model_with_ablation(layers_to_ablate)

# Display the summary to confirm the ablation layers are included
face_model_with_ablation.summary()

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_2".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_2'), name='input_2',
description="created by layer 'input_2'")

Model: "model_1"
______________________________________________________________________
____________________________
 Layer (type)                   Output Shape         Param #
Connected to
======================================================================
============================
 input_2 (InputLayer)           multiple             0
['input_2[0][0]']


 ablated_input_2 (Lambda)       (None, 224, 224, 3)  0
['input_2[1][0]']
```

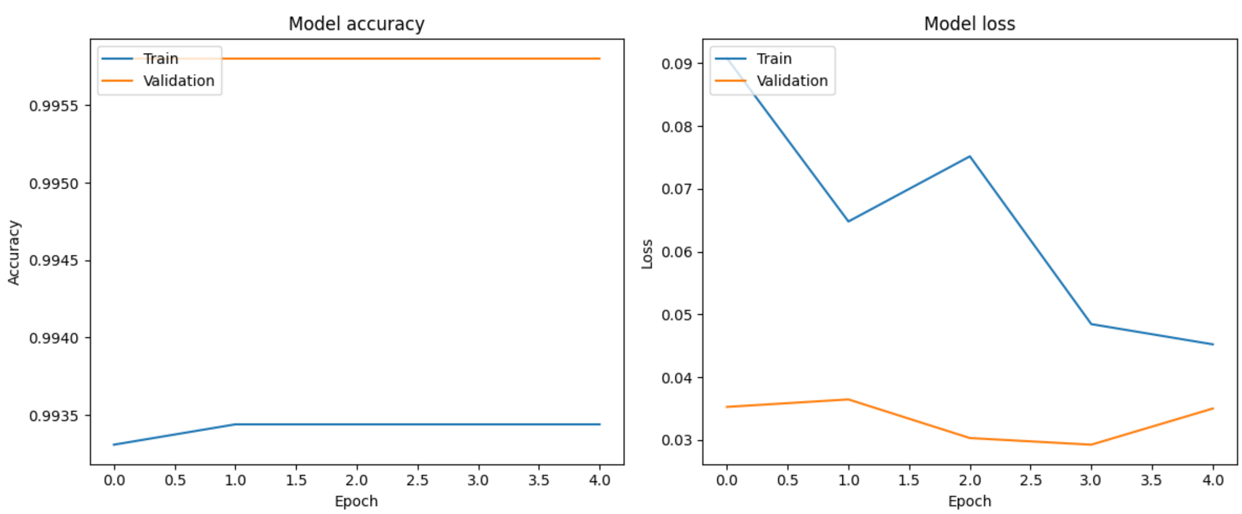
```
 conv1_1 (Conv2D)                (None, 224, 224, 64  1792
['ablated_input_2[0][0]']
                                )

 ablated_conv1_1 (Lambda)        (None, 224, 224, 64  0
['conv1_1[1][0]']
                                )

 conv1_2 (Conv2D)                (None, 224, 224, 64  36928
['ablated_conv1_1[0][0]']
                                )

 ablated_conv1_2 (Lambda)        (None, 224, 224, 64  0
['conv1_2[1][0]']
                                )

 pool1 (MaxPooling2D)            (None, 112, 112, 64  0
['ablated_conv1_2[0][0]']
                                )

 ablated_pool1 (Lambda)          (None, 112, 112, 64  0
['pool1[1][0]']
                                )

 conv2_1 (Conv2D)                (None, 112, 112, 12  73856
['ablated_pool1[0][0]']
                                8)

 ablated_conv2_1 (Lambda)        (None, 112, 112, 12  0
['conv2_1[1][0]']
                                8)

 conv2_2 (Conv2D)                (None, 112, 112, 12  147584
['ablated_conv2_1[0][0]']
```

```
                                8)


 ablated_conv2_2 (Lambda)       (None, 112, 112, 12  0
['conv2_2[1][0]']
                                8)


 pool2 (MaxPooling2D)           (None, 56, 56, 128)  0
['ablated_conv2_2[0][0]']


 ablated_pool2 (Lambda)         (None, 56, 56, 128)  0
['pool2[1][0]']


 conv3_1 (Conv2D)               (None, 56, 56, 256)  295168
['ablated_pool2[0][0]']


 ablated_conv3_1 (Lambda)       (None, 56, 56, 256)  0
['conv3_1[1][0]']


 conv3_2 (Conv2D)               (None, 56, 56, 256)  590080
['ablated_conv3_1[0][0]']


 ablated_conv3_2 (Lambda)       (None, 56, 56, 256)  0
['conv3_2[1][0]']


 conv3_3 (Conv2D)               (None, 56, 56, 256)  590080
['ablated_conv3_2[0][0]']


 ablated_conv3_3 (Lambda)       (None, 56, 56, 256)  0
['conv3_3[1][0]']


 pool3 (MaxPooling2D)           (None, 28, 28, 256)  0
['ablated_conv3_3[0][0]']


 ablated_pool3 (Lambda)         (None, 28, 28, 256)  0
['pool3[1][0]']


 conv4_1 (Conv2D)               (None, 28, 28, 512)  1180160
```

```
['ablated_pool3[0][0]']


 ablated_conv4_1 (Lambda)       (None, 28, 28, 512)  0
['conv4_1[1][0]']


 conv4_2 (Conv2D)               (None, 28, 28, 512)  2359808
['ablated_conv4_1[0][0]']


 ablated_conv4_2 (Lambda)       (None, 28, 28, 512)  0
['conv4_2[1][0]']


 conv4_3 (Conv2D)               (None, 28, 28, 512)  2359808
['ablated_conv4_2[0][0]']


 ablated_conv4_3 (Lambda)       (None, 28, 28, 512)  0
['conv4_3[1][0]']


 pool4 (MaxPooling2D)           (None, 14, 14, 512)  0
['ablated_conv4_3[0][0]']


 ablated_pool4 (Lambda)         (None, 14, 14, 512)  0
['pool4[1][0]']


 conv5_1 (Conv2D)               (None, 14, 14, 512)  2359808
['ablated_pool4[0][0]']


 ablated_conv5_1 (Lambda)       (None, 14, 14, 512)  0
['conv5_1[1][0]']


 conv5_2 (Conv2D)               (None, 14, 14, 512)  2359808
['ablated_conv5_1[0][0]']


 ablated_conv5_2 (Lambda)       (None, 14, 14, 512)  0
['conv5_2[1][0]']


 conv5_3 (Conv2D)               (None, 14, 14, 512)  2359808
['ablated_conv5_2[0][0]']
```

```
 ablated_conv5_3 (Lambda)       (None, 14, 14, 512)  0
['conv5_3[1][0]']


 pool5 (MaxPooling2D)           (None, 7, 7, 512)    0
['ablated_conv5_3[0][0]']


 ablated_pool5 (Lambda)         (None, 7, 7, 512)    0
['pool5[1][0]']


 global_average_pooling2d_1 (Gl  (None, 512)         0
['ablated_pool5[0][0]']
 obalAveragePooling2D)



 ablated_global_average_pooling  (None, 512)         0
['global_average_pooling2d_1[1][0
 2d_1 (Lambda)                                                     ]']



 flatten_1 (Flatten)            (None, 512)          0
['ablated_global_average_pooling2

d_1[0][0]']


 dense_1 (Dense)                (None, 1)            513
['flatten_1[0][0]']


======================================================================
============================
Total params: 14,715,201
Trainable params: 14,715,201
Non-trainable params: 0
______________________________________________________________________
____________________________

# Train the ablated model for layers conv4_3 to conv5_3
from tensorflow.keras.callbacks import ModelCheckpoint, EarlyStopping
# Set up callbacks
checkpoint = ModelCheckpoint('ablation_model_1.h5',
save_best_only=True, monitor='val_loss', mode='min')
early_stop = EarlyStopping(monitor='val_loss', patience=10,
restore_best_weights=True)
```

```
history_ablation = face_model_with_ablation.fit(X_train_deficit,
y_train_deficit, validation_split=0.2, epochs=5, batch_size=32,
callbacks=[checkpoint, early_stop])

Epoch 1/5
239/239 [==============================] - 60s 252ms/step - loss:
0.0908 - accuracy: 0.9933 - val_loss: 0.0353 - val_accuracy: 0.9958
Epoch 2/5
239/239 [==============================] - 59s 248ms/step - loss:
0.0648 - accuracy: 0.9934 - val_loss: 0.0365 - val_accuracy: 0.9958
Epoch 3/5
239/239 [==============================] - 60s 251ms/step - loss:
0.0752 - accuracy: 0.9934 - val_loss: 0.0303 - val_accuracy: 0.9958
Epoch 4/5
239/239 [==============================] - 59s 248ms/step - loss:
0.0484 - accuracy: 0.9934 - val_loss: 0.0292 - val_accuracy: 0.9958
Epoch 5/5
239/239 [==============================] - 59s 248ms/step - loss:
0.0452 - accuracy: 0.9934 - val_loss: 0.0350 - val_accuracy: 0.9958

# Plot metrics for this ablation
plot_model_metrics(history_ablation)
```



Testing the Ablated Model

```
import numpy as np
from tensorflow.keras.backend import clear_session

def calculate_accuracy(rebuild_model_func, rebuild_model_args,
test_images, test_labels, threshold=0.5, num_runs=5):
    """
    Evaluate the model over a number of runs and return the average
accuracy.
```

```
    :param rebuild_model_func: Function to rebuild the model.
    :param rebuild_model_args: Positional arguments for the rebuild
model function.
    :param rebuild_model_kwargs: Keyword arguments for the rebuild
model function.
    :param test_images: Array of test images.
    :param test_labels: Array of true labels for the test images.
    :param threshold: Threshold to convert predicted probabilities to
binary predictions.
    :param num_runs: Number of runs to perform.
    :return: Average accuracy over the specified number of runs.
    """
    total_accuracy = 0

    # Perform training and evaluation in a loop
    for run in range(num_runs):
        # Reset the session
        clear_session()
        # Rebuild the model with the provided function and arguments
        model = rebuild_model_func(*rebuild_model_args)

        # Train the model (omitted for brevity)

        # Make predictions using the model
        predictions = model.predict(test_images)

        # Convert predictions to binary using the defined threshold
        binary_predictions = (predictions >
threshold).astype(int).flatten()

        # Calculate accuracy
        num_correct = np.sum(binary_predictions == test_labels)
        accuracy = num_correct / len(test_labels)

        # Accumulate total accuracy
        total_accuracy += accuracy
        print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

    # Calculate the average accuracy over all runs
    avg_accuracy = total_accuracy / num_runs
    print(f"Average Accuracy over {num_runs} runs: {avg_accuracy *
100:.2f}%")
    return avg_accuracy, binary_predictions

import gc

del accuracy, binary_predictions, test_labels, test_images
gc.collect()
```

```
129957
```

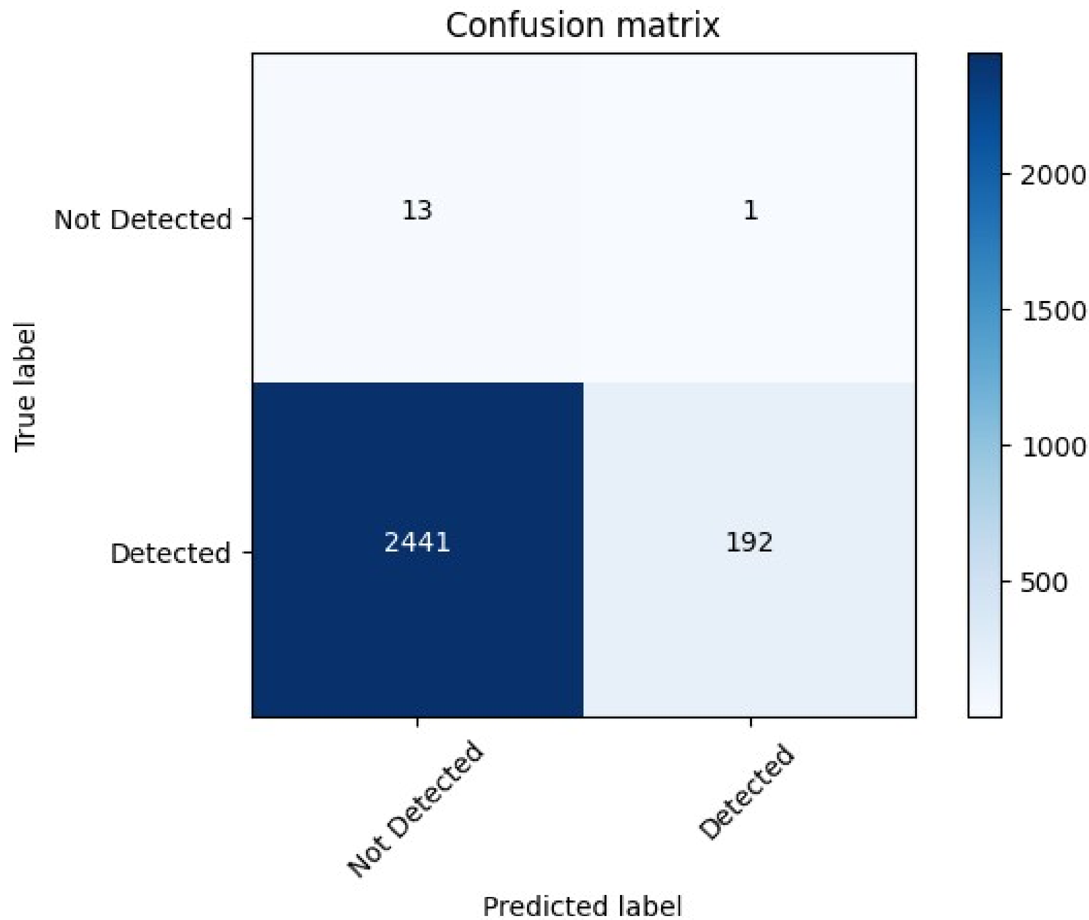
```
accuracy, binary_predictions_normal =
calculate_accuracy(rebuild_model_func=build_model_with_ablation,
    rebuild_model_args=(layers_to_ablate,),
    test_images=X_test,
    test_labels=y_test)
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 95ms/step
Run 1: Accuracy = 47.07%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 97ms/step
Run 2: Accuracy = 88.06%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 99ms/step
Run 3: Accuracy = 41.71%
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 98ms/step
Run 4: Accuracy = 37.44%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 5: Accuracy = 7.74%
Average Accuracy over 5 runs: 44.40%
```

```python
# performace on normal data
y_true = y_test
y_pred = binary_predictions_normal

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9948186528497409
Recall: 0.07292062286365363
F1 Score: 0.13588110403397025
```




```
accuracy, binary_predictions_brows =
calculate_accuracy(rebuild_model_func=build_model_with_ablation,
    rebuild_model_args=(layers_to_ablate,),
    test_images=X_test_brows,
    test_labels=y_test_brows)

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 93ms/step
Run 1: Accuracy = 0.83%
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 93ms/step
Run 2: Accuracy = 98.53%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 93ms/step
Run 3: Accuracy = 32.00%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 93ms/step
Run 4: Accuracy = 25.35%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
```

```
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 94ms/step
Run 5: Accuracy = 72.53%
Average Accuracy over 5 runs: 45.85%
```

```
accuracy, binary_predictions_brows =
calculate_accuracy(rebuild_model_func=build_model_with_ablation,
    rebuild_model_args=(layers_to_ablate,),
    test_images=X_test_brows,
    test_labels=y_test_brows)
```

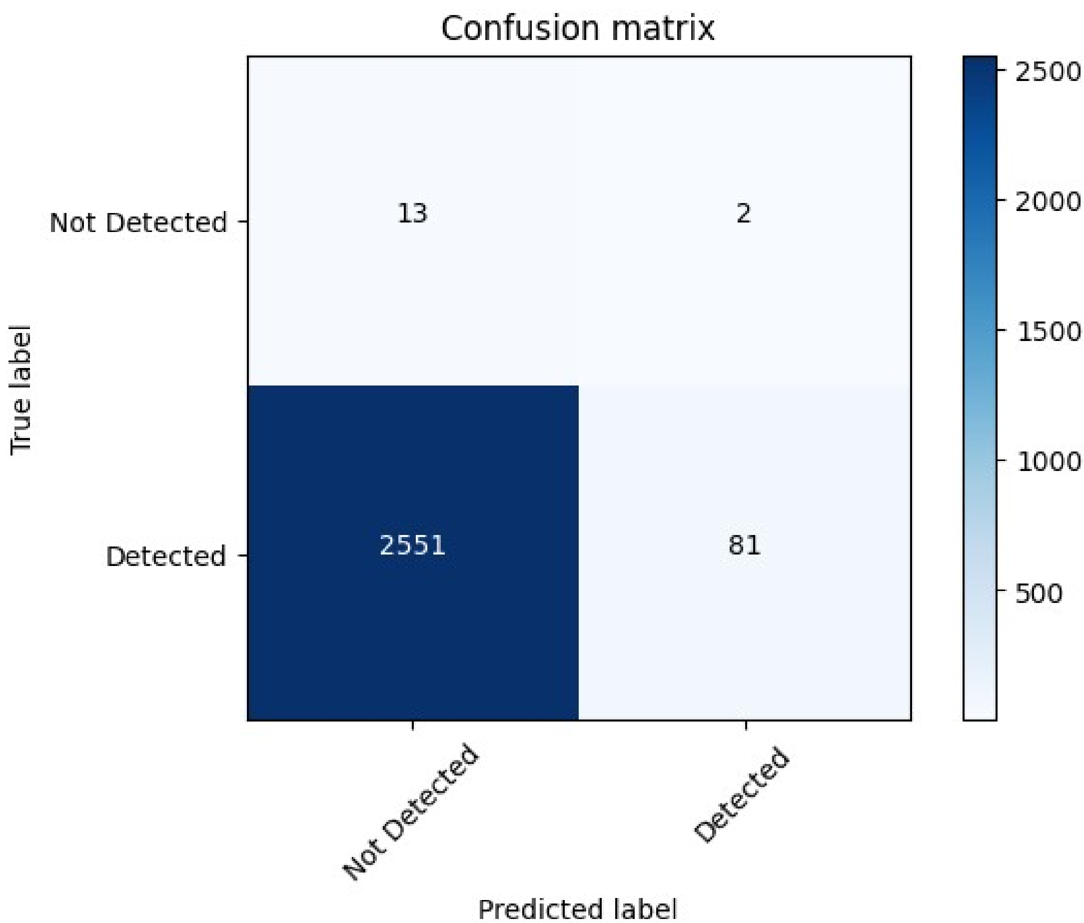
```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 93ms/step
Run 1: Accuracy = 35.40%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 94ms/step
Run 2: Accuracy = 97.77%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
```

```
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 95ms/step
Run 3: Accuracy = 24.10%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 4: Accuracy = 27.43%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 97ms/step
Run 5: Accuracy = 3.55%
Average Accuracy over 5 runs: 37.65%
```

```python
# performace on masked_brows
y_true = y_test_brows
y_pred = binary_predictions_brows

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)
```

```
# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9759036144578314
Recall: 0.030775075987841946
F1 Score: 0.059668508287292824
```




```
accuracy, binary_predictions =
calculate_accuracy(rebuild_model_func=build_model_with_ablation,
    rebuild_model_args=(layers_to_ablate,),
    test_images=X_test_eyes,
    test_labels=y_test_eyes)
```

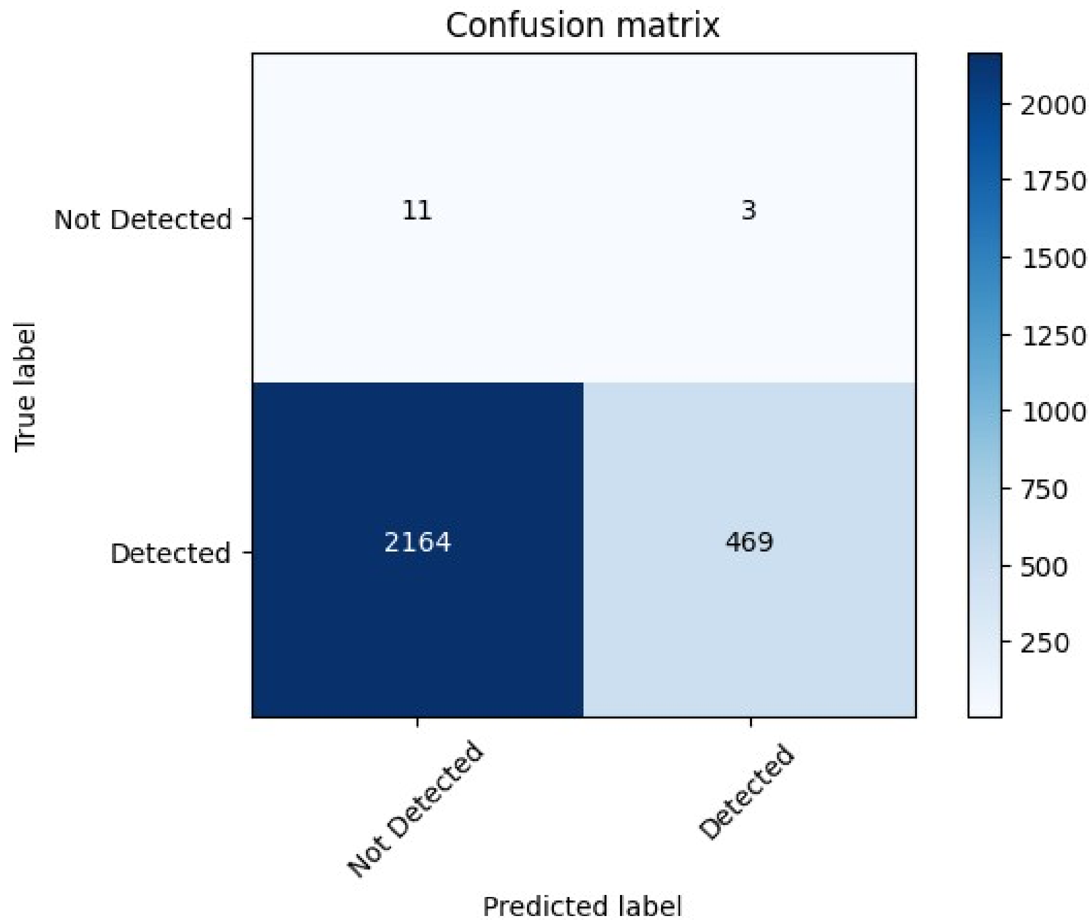
```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
```

```
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 91ms/step
Run 1: Accuracy = 94.11%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 92ms/step
Run 2: Accuracy = 94.79%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 92ms/step
Run 3: Accuracy = 46.88%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")
```

```
83/83 [==============================] - 8s 92ms/step
Run 4: Accuracy = 16.06%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 92ms/step
Run 5: Accuracy = 18.21%
Average Accuracy over 5 runs: 54.01%
```

```python
# performace on masked eyes
y_true = test_labels
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9936440677966102
Recall: 0.17812381314090392
F1 Score: 0.3020933977455717
```




```
# Test the ablated model - masked nose
test_images = X_test_nose # Load your test images here
test_labels = y_test_nose # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

# Make predictions using the model
# predictions = final_model.predict(test_images)
predictions = face_model_with_ablation.predict(test_images)
binary_predictions = (predictions.max(axis=1) > threshold).astype(int)

# Calculate accuracy
num_correct = 0
total_images = len(test_images)

for i in range(total_images):
    predicted_class = binary_predictions[i]
    true_class = test_labels[i]
    if predicted_class == true_class:
        num_correct += 1
```

```
accuracy = num_correct / total_images
print("Face model with abalation accuracy [Ablated layers: conv4_3,
conv5_1, conv5_2, conv5_3]:", accuracy)
```

```
83/83 [==============================] - 8s 92ms/step
Face model with abalation accuracy [Ablated layers: conv4_3, conv5_1,
conv5_2, conv5_3]: 0.36607480166225914
```

```
accuracy, binary_predictions =
calculate_accuracy(rebuild_model_func=build_model_with_ablation,
    rebuild_model_args=(layers_to_ablate,),
    test_images=X_test_nose,
    test_labels=y_test_nose)
```

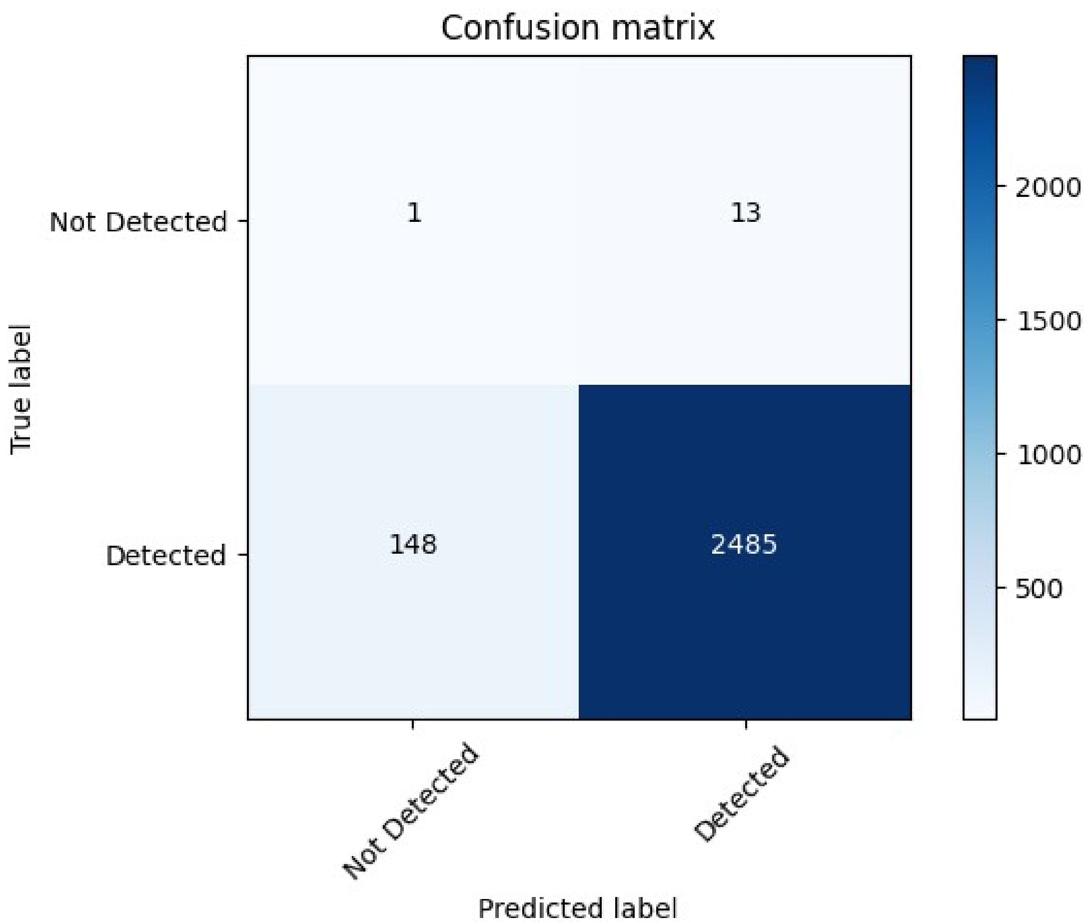
```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 93ms/step
Run 1: Accuracy = 98.90%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 94ms/step
Run 2: Accuracy = 0.98%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
```

```
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 95ms/step
Run 3: Accuracy = 29.58%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 4: Accuracy = 68.42%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 5: Accuracy = 93.92%
Average Accuracy over 5 runs: 58.36%
```

```
# performace on masked nose
y_true = y_test_nose
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
```

```
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9947958366693355
Recall: 0.943790353209267
F1 Score: 0.9686221009549795
```




```
# Test the ablated model - masked mouth
test_images = X_test_mouth # Load your test images here
test_labels = y_test_mouth # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

# Make predictions using the model
# predictions = final_model.predict(test_images)
predictions = face_model_with_ablation.predict(test_images)
binary_predictions = (predictions.max(axis=1) > threshold).astype(int)

# Calculate accuracy
num_correct = 0
```

```python
total_images = len(test_images)

for i in range(total_images):
    predicted_class = binary_predictions[i]
    true_class = test_labels[i]
    if predicted_class == true_class:
        num_correct += 1

accuracy = num_correct / total_images
print("Face model with abalation accuracy [Ablated layers: conv4_3,
conv5_1, conv5_2, conv5_3]:", accuracy)
```

```
83/83 [==============================] - 8s 92ms/step
Face model with abalation accuracy [Ablated layers: conv4_3, conv5_1,
conv5_2, conv5_3]: 0.47714393653192294
```

```python
accuracy, binary_predictions =
calculate_accuracy(rebuild_model_func=build_model_with_ablation,
    rebuild_model_args=(layers_to_ablate,),
    test_images=X_test_mouth,
    test_labels=y_test_mouth)
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 95ms/step
Run 1: Accuracy = 51.15%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 95ms/step
Run 2: Accuracy = 73.59%
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 95ms/step
Run 3: Accuracy = 93.39%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

41/83 [=============>................] - ETA: 3s

----------------------------------------------------------------------
-----
KeyboardInterrupt                         Traceback (most recent call
last)
<ipython-input-141-75bb363f3428> in <cell line: 1>()
----> 1 accuracy, binary_predictions =
calculate_accuracy(rebuild_model_func=build_model_with_ablation,
      2     rebuild_model_args=(layers_to_ablate,),
      3     test_images=X_test_mouth,
      4     test_labels=y_test_mouth)

<ipython-input-132-c2eb25a52daf> in
calculate_accuracy(rebuild_model_func, rebuild_model_args,
test_images, test_labels, threshold, num_runs)
     27
     28         # Make predictions using the model
---> 29         predictions = model.predict(test_images)
     30
     31         # Convert predictions to binary using the defined
threshold
```

```
/usr/local/lib/python3.10/dist-packages/keras/utils/traceback_utils.py
in error_handler(*args, **kwargs)
     63         filtered_tb = None
     64         try:
---> 65             return fn(*args, **kwargs)
     66         except Exception as e:
     67             filtered_tb =
_process_traceback_frames(e.__traceback__)

/usr/local/lib/python3.10/dist-packages/keras/engine/training.py in
predict(self, x, batch_size, verbose, steps, callbacks,
max_queue_size, workers, use_multiprocessing)
   2378             for _, iterator in
data_handler.enumerate_epochs():  # Single epoch.
   2379                 with data_handler.catch_stop_iteration():
-> 2380                     for step in data_handler.steps():
   2381                         callbacks.on_predict_batch_begin(step)
   2382                         tmp_batch_outputs =
self.predict_function(iterator)

/usr/local/lib/python3.10/dist-packages/keras/engine/data_adapter.py
in steps(self)
   1373             if self._insufficient_data:  # Set by
`catch_stop_iteration`.
   1374                 break
-> 1375             original_spe =
self._steps_per_execution.numpy().item()
   1376             can_run_full_execution = (
   1377                 original_spe == 1

/usr/local/lib/python3.10/dist-packages/tensorflow/python/ops/resource
_variable_ops.py in numpy(self)
    687   def numpy(self):
    688     if context.executing_eagerly():
--> 689       return self.read_value().numpy()
    690     raise NotImplementedError(
    691         "numpy() is only available when eager execution is
enabled.")

/usr/local/lib/python3.10/dist-packages/tensorflow/python/framework/
ops.py in numpy(self)
    392     """
    393     # TODO(slebedev): Consider avoiding a copy for non-CPU or
remote tensors.
--> 394     maybe_arr = self._numpy()  # pylint: disable=protected-
access
    395     return maybe_arr.copy() if isinstance(maybe_arr,
np.ndarray) else maybe_arr
    396
```

```
/usr/local/lib/python3.10/dist-packages/tensorflow/python/framework/
ops.py in _numpy(self)
    358   def _numpy(self):
    359     try:
--> 360       return self._numpy_internal()
    361     except core._NotOkStatusException as e:  # pylint:
disable=protected-access
    362       raise core._status_to_exception(e) from None  # pylint:
disable=protected-access

KeyboardInterrupt:
```

```
# performace on masked mouth
y_true = y_test_mouth
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

Ablation Model [Grad-CAM Layers]

```
# Specify the layers to be ablated based on Grad-CAM results
layers_to_ablate = [ 'conv3_2', 'conv4_2', 'conv5_3' ]

# Build the model with feature ablation
face_model_with_ablation_2 =
build_model_with_ablation(layers_to_ablate)

# Display the summary to confirm the ablation layers are included
face_model_with_ablation_2.summary()
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_2".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_2'), name='input_2',
description="created by layer 'input_2'")
```

```
Model: "model_1"
__________________________________________________________________________________________________
 Layer (type)                   Output Shape         Param #     Connected to
==================================================================================================
 input_2 (InputLayer)           multiple             0           ['input_2[0][0]']

 ablated_input_2 (Lambda)       (None, 224, 224, 3)  0           ['input_2[1][0]']

 conv1_1 (Conv2D)               (None, 224, 224, 64  1792        ['ablated_input_2[0][0]']
                                )

 ablated_conv1_1 (Lambda)       (None, 224, 224, 64  0           ['conv1_1[1][0]']
                                )

 conv1_2 (Conv2D)               (None, 224, 224, 64  36928       ['ablated_conv1_1[0][0]']
                                )

 ablated_conv1_2 (Lambda)       (None, 224, 224, 64  0           ['conv1_2[1][0]']
                                )

 pool1 (MaxPooling2D)           (None, 112, 112, 64  0           ['ablated_conv1_2[0][0]']
                                )

 ablated_pool1 (Lambda)         (None, 112, 112, 64  0           ['pool1[1][0]']
                                )
```

```
 conv2_1 (Conv2D)               (None, 112, 112, 12  73856
['ablated_pool1[0][0]']
                                8)


 ablated_conv2_1 (Lambda)       (None, 112, 112, 12  0
['conv2_1[1][0]']
                                8)


 conv2_2 (Conv2D)               (None, 112, 112, 12  147584
['ablated_conv2_1[0][0]']
                                8)


 ablated_conv2_2 (Lambda)       (None, 112, 112, 12  0
['conv2_2[1][0]']
                                8)


 pool2 (MaxPooling2D)           (None, 56, 56, 128)  0
['ablated_conv2_2[0][0]']


 ablated_pool2 (Lambda)         (None, 56, 56, 128)  0
['pool2[1][0]']


 conv3_1 (Conv2D)               (None, 56, 56, 256)  295168
['ablated_pool2[0][0]']


 ablated_conv3_1 (Lambda)       (None, 56, 56, 256)  0
['conv3_1[1][0]']


 conv3_2 (Conv2D)               (None, 56, 56, 256)  590080
['ablated_conv3_1[0][0]']


 ablated_conv3_2 (Lambda)       (None, 56, 56, 256)  0
['conv3_2[1][0]']


 conv3_3 (Conv2D)               (None, 56, 56, 256)  590080
['ablated_conv3_2[0][0]']
```

```
 ablated_conv3_3 (Lambda)       (None, 56, 56, 256)  0
['conv3_3[1][0]']


 pool3 (MaxPooling2D)           (None, 28, 28, 256)  0
['ablated_conv3_3[0][0]']


 ablated_pool3 (Lambda)         (None, 28, 28, 256)  0
['pool3[1][0]']


 conv4_1 (Conv2D)               (None, 28, 28, 512)  1180160
['ablated_pool3[0][0]']


 ablated_conv4_1 (Lambda)       (None, 28, 28, 512)  0
['conv4_1[1][0]']


 conv4_2 (Conv2D)               (None, 28, 28, 512)  2359808
['ablated_conv4_1[0][0]']


 ablated_conv4_2 (Lambda)       (None, 28, 28, 512)  0
['conv4_2[1][0]']


 conv4_3 (Conv2D)               (None, 28, 28, 512)  2359808
['ablated_conv4_2[0][0]']


 ablated_conv4_3 (Lambda)       (None, 28, 28, 512)  0
['conv4_3[1][0]']


 pool4 (MaxPooling2D)           (None, 14, 14, 512)  0
['ablated_conv4_3[0][0]']


 ablated_pool4 (Lambda)         (None, 14, 14, 512)  0
['pool4[1][0]']


 conv5_1 (Conv2D)               (None, 14, 14, 512)  2359808
['ablated_pool4[0][0]']


 ablated_conv5_1 (Lambda)       (None, 14, 14, 512)  0
['conv5_1[1][0]']
```

```
 conv5_2 (Conv2D)               (None, 14, 14, 512)  2359808
['ablated_conv5_1[0][0]']


 ablated_conv5_2 (Lambda)       (None, 14, 14, 512)  0
['conv5_2[1][0]']


 conv5_3 (Conv2D)               (None, 14, 14, 512)  2359808
['ablated_conv5_2[0][0]']


 ablated_conv5_3 (Lambda)       (None, 14, 14, 512)  0
['conv5_3[1][0]']


 pool5 (MaxPooling2D)           (None, 7, 7, 512)    0
['ablated_conv5_3[0][0]']


 ablated_pool5 (Lambda)         (None, 7, 7, 512)    0
['pool5[1][0]']


 global_average_pooling2d_1 (Gl  (None, 512)         0
['ablated_pool5[0][0]']
 obalAveragePooling2D)



 ablated_global_average_pooling  (None, 512)         0
['global_average_pooling2d_1[1][0
 2d_1 (Lambda)                                                             ]']



 flatten_1 (Flatten)            (None, 512)          0
['ablated_global_average_pooling2

d_1[0][0]']


 dense_1 (Dense)                (None, 1)            513
['flatten_1[0][0]']


======================================================================
============================
Total params: 14,715,201
```

```
Trainable params: 14,715,201
Non-trainable params: 0
____________________________________________________________________________________________________

# Train the Ablation Model 2
# Train the ablated model for layers conv4_3 to conv5_3
from tensorflow.keras.callbacks import ModelCheckpoint, EarlyStopping
# Set up callbacks
checkpoint = ModelCheckpoint('feature_ablation_2.h5',
save_best_only=True, monitor='val_loss', mode='min')
early_stop = EarlyStopping(monitor='val_loss', patience=2,
restore_best_weights=True)

history_ablation_2 = face_model_with_ablation_2.fit(X_train_deficit,
y_train_deficit, validation_split = 0.2, epochs=5, batch_size=32,
callbacks=[checkpoint, early_stop])

Epoch 1/5
239/239 [==============================] - 64s 253ms/step - loss:
239.4181 - accuracy: 0.9902 - val_loss: 0.0783 - val_accuracy: 0.9921
Epoch 2/5
 33/239 [===>..........................] - ETA: 46s - loss: 0.0613 -
accuracy: 0.9934

----------------------------------------------------------------------
-----
KeyboardInterrupt                         Traceback (most recent call
last)
<ipython-input-174-deee3d88beb3> in <cell line: 8>()
      6 early_stop = EarlyStopping(monitor='val_loss', patience=2,
restore_best_weights=True)
      7
----> 8 history_ablation_2 =
face_model_with_ablation_2.fit(X_train_deficit, y_train_deficit,
validation_split = 0.2, epochs=5, batch_size=32,
callbacks=[checkpoint, early_stop])

/usr/local/lib/python3.10/dist-packages/keras/utils/traceback_utils.py
in error_handler(*args, **kwargs)
     63         filtered_tb = None
     64         try:
---> 65             return fn(*args, **kwargs)
     66         except Exception as e:
     67             filtered_tb =
_process_traceback_frames(e.__traceback__)

/usr/local/lib/python3.10/dist-packages/keras/engine/training.py in
fit(self, x, y, batch_size, epochs, verbose, callbacks,
validation_split, validation_data, shuffle, class_weight,
```

```
sample_weight, initial_epoch, steps_per_epoch, validation_steps,
validation_batch_size, validation_freq, max_queue_size, workers,
use_multiprocessing)
   1683                         ):
   1684
callbacks.on_train_batch_begin(step)
-> 1685                            tmp_logs =
self.train_function(iterator)
   1686                            if data_handler.should_sync:
   1687                                context.async_wait()

/usr/local/lib/python3.10/dist-packages/tensorflow/python/util/traceba
ck_utils.py in error_handler(*args, **kwargs)
    148     filtered_tb = None
    149     try:
--> 150       return fn(*args, **kwargs)
    151     except Exception as e:
    152       filtered_tb = _process_traceback_frames(e.__traceback__)

/usr/local/lib/python3.10/dist-packages/tensorflow/python/eager/polymo
rphic_function/polymorphic_function.py in __call__(self, *args,
**kwds)
    830
    831       with OptionalXlaContext(self._jit_compile):
--> 832         result = self._call(*args, **kwds)
    833
    834       new_tracing_count =
self.experimental_get_tracing_count()

/usr/local/lib/python3.10/dist-packages/tensorflow/python/eager/polymo
rphic_function/polymorphic_function.py in _call(self, *args, **kwds)
    866       # In this case we have created variables on the first
call, so we run the
    867       # defunned version which is guaranteed to never create
variables.
--> 868       return tracing_compilation.call_function(
    869           args, kwds, self._no_variable_creation_config
    870       )

/usr/local/lib/python3.10/dist-packages/tensorflow/python/eager/polymo
rphic_function/tracing_compilation.py in call_function(args, kwargs,
tracing_options)
    137   bound_args = function.function_type.bind(*args, **kwargs)
    138   flat_inputs =
function.function_type.unpack_inputs(bound_args)
--> 139   return function._call_flat(  # pylint: disable=protected-
access
    140       flat_inputs, captured_inputs=function.captured_inputs
    141   )
```

```
/usr/local/lib/python3.10/dist-packages/tensorflow/python/eager/polymo
rphic_function/concrete_function.py in _call_flat(self, tensor_inputs,
captured_inputs)
   1321         and executing_eagerly):
   1322       # No tape is watching; skip to running the function.
-> 1323       return self._inference_function.call_preflattened(args)
   1324     forward_backward =
self._select_forward_and_backward_functions(
   1325         args,

/usr/local/lib/python3.10/dist-packages/tensorflow/python/eager/polymo
rphic_function/atomic_function.py in call_preflattened(self, args)
    214   def call_preflattened(self, args: Sequence[core.Tensor]) ->
Any:
    215     """Calls with flattened tensor inputs and returns the
structured output."""
--> 216     flat_outputs = self.call_flat(*args)
    217     return self.function_type.pack_output(flat_outputs)
    218

/usr/local/lib/python3.10/dist-packages/tensorflow/python/eager/polymo
rphic_function/atomic_function.py in call_flat(self, *args)
    249         with record.stop_recording():
    250           if self._bound_context.executing_eagerly():
--> 251             outputs = self._bound_context.call_function(
    252                 self.name,
    253                 list(args),

/usr/local/lib/python3.10/dist-packages/tensorflow/python/eager/contex
t.py in call_function(self, name, tensor_inputs, num_outputs)
   1484     cancellation_context = cancellation.context()
   1485     if cancellation_context is None:
-> 1486       outputs = execute.execute(
   1487           name.decode("utf-8"),
   1488           num_outputs=num_outputs,

/usr/local/lib/python3.10/dist-packages/tensorflow/python/eager/execut
e.py in quick_execute(op_name, num_outputs, inputs, attrs, ctx, name)
     51   try:
     52     ctx.ensure_initialized()
---> 53     tensors = pywrap_tfe.TFE_Py_Execute(ctx._handle,
device_name, op_name,
     54                                         inputs, attrs,
num_outputs)
     55   except core._NotOkStatusException as e:

KeyboardInterrupt:

# Plot the metrics
plot_model_metrics(history_ablation_2)
```

Testing Abalation Model 2

```
print(layers_to_ablate)
```

```
['conv3_2', 'conv4_2', 'conv5_3']
```

Normal

```
accuracy, binary_predictions_normal =
calculate_accuracy(rebuild_model_func=build_model_with_ablation,
    rebuild_model_args=(layers_to_ablate,),
    test_images=X_test,
    test_labels=y_test)

# performace on normal data
y_true = y_test
y_pred = binary_predictions_normal

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

Eyebrows

```
# Call the function with arguments for a specific model rebuild
function
accuracy, binary_predictions_brows =
calculate_accuracy(rebuild_model_func=build_model_with_ablation,
    rebuild_model_args=(layers_to_ablate,),
    test_images=X_test_brows,
    test_labels=y_test_brows)

# performace on normal data
y_true = y_test_brows
y_pred = binary_predictions_brows

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

Eyes

```
# Call the function with arguments for a specific model rebuild
function
accuracy, binary_predictions_eyes =
calculate_accuracy(rebuild_model_func=build_model_with_ablation,
    rebuild_model_args=(layers_to_ablate,),
    test_images=X_test_eyes,
    test_labels=y_test_eyes)

# performace on normal data
y_true = y_test_eyes
y_pred = binary_predictions_eyes

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

Nose

```
# Call the function with arguments for a specific model rebuild
function
accuracy, binary_predictions_nose =
calculate_accuracy(rebuild_model_func=build_model_with_ablation,
    rebuild_model_args=(layers_to_ablate,),
    test_images=X_test_nose,
    test_labels=y_test_nose)

# performace on normal data
y_true = y_test_nose
y_pred = binary_predictions_nose

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

Mouth

```
accuracy, binary_predictions_mouth =
calculate_accuracy(rebuild_model_func=build_model_with_ablation,
    rebuild_model_args=(layers_to_ablate,),
    test_images=X_test_mouth,
    test_labels=y_test_mouth)

# performace on normal data
y_true = y_test_mouth
y_pred = binary_predictions_mouth

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)

calculate_accuracy(rebuild_model_func=build_model_with_ablation,
    rebuild_model_args=(layers_to_ablate,),
    test_images=X_test_nose,
    test_labels=y_test_nose)

calculate_accuracy(rebuild_model_func=build_model_with_ablation,
    rebuild_model_args=(layers_to_ablate,),
    test_images=X_test_mouth,
    test_labels=y_test_mouth)
```

Approach 2: Noise Injection

```
from keras.models import clone_model
from keras.layers import GaussianNoise

def add_noise_to_specific_layers(base_model, noise_layers,
noise_level=0.1):
    """
    Adds Gaussian noise to the output of specific layers without
modifying the base model.

    :param base_model: The base Keras model.
    :param noise_layers: A list of layer names to which noise should
be added.
    :param noise_level: The standard deviation of the noise
distribution.
    :return: A new model with noise injection.
    """
    # Clone the base model
```

```
    model_clone = clone_model(base_model)
    model_clone.set_weights(base_model.get_weights())

    # Rebuild model architecture and add noise to the specified layers
    x = model_clone.input
    for layer in model_clone.layers:
        if layer.name in noise_layers:
            # Add Gaussian noise after the specified layer
            x = GaussianNoise(noise_level)(layer(x))
        else:
            x = layer(x)

    # Create the new model with noise injection
    model_with_noise = Model(inputs=model_clone.input, outputs=x)
    model_with_noise.compile(optimizer='adam',
loss='binary_crossentropy', metrics=['accuracy'])

    return model_with_noise

clear_session()
face_model = build_model()
# Specify the layers to be ablated based on Grad-CAM results
noisy_layers = ['conv3_2', 'conv4_2', 'conv5_3']

# Build the model with feature ablation
noise_face_model = add_noise_to_specific_layers(face_model,
noisy_layers, noise_level=0.8)


# Display the summary to confirm the ablation layers are included
noise_face_model.summary()
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

Model: "model_1"
________________________________________________________________________
____________________________
 Layer (type)                    Output Shape         Param #
Connected to
========================================================================
============================
```

```
 input_1 (InputLayer)           multiple             0
['input_1[0][0]']


 conv1_1 (Conv2D)               (None, 224, 224, 64  1792
['input_1[1][0]']
                                )



 conv1_2 (Conv2D)               (None, 224, 224, 64  36928
['conv1_1[1][0]']
                                )



 pool1 (MaxPooling2D)           (None, 112, 112, 64  0
['conv1_2[1][0]']
                                )



 conv2_1 (Conv2D)               (None, 112, 112, 12  73856
['pool1[1][0]']
                                8)



 conv2_2 (Conv2D)               (None, 112, 112, 12  147584
['conv2_1[1][0]']
                                8)



 pool2 (MaxPooling2D)           (None, 56, 56, 128)  0
['conv2_2[1][0]']


 conv3_1 (Conv2D)               (None, 56, 56, 256)  295168
['pool2[1][0]']


 conv3_2 (Conv2D)               (None, 56, 56, 256)  590080
['conv3_1[1][0]']


 gaussian_noise (GaussianNoise)  (None, 56, 56, 256)  0
['conv3_2[1][0]']


 conv3_3 (Conv2D)               (None, 56, 56, 256)  590080
```

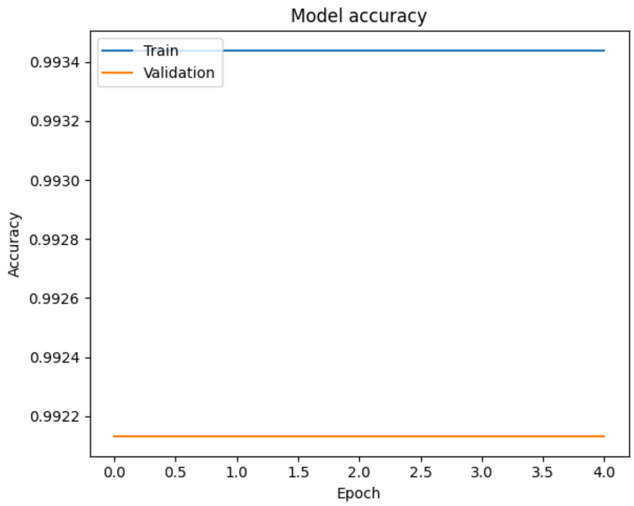
```
['gaussian_noise[0][0]']


 pool3 (MaxPooling2D)           (None, 28, 28, 256)  0
['conv3_3[1][0]']


 conv4_1 (Conv2D)               (None, 28, 28, 512)  1180160
['pool3[1][0]']


 conv4_2 (Conv2D)               (None, 28, 28, 512)  2359808
['conv4_1[1][0]']


 gaussian_noise_1 (GaussianNois  (None, 28, 28, 512)  0
['conv4_2[1][0]']
 e)



 conv4_3 (Conv2D)               (None, 28, 28, 512)  2359808
['gaussian_noise_1[0][0]']


 pool4 (MaxPooling2D)           (None, 14, 14, 512)  0
['conv4_3[1][0]']


 conv5_1 (Conv2D)               (None, 14, 14, 512)  2359808
['pool4[1][0]']


 conv5_2 (Conv2D)               (None, 14, 14, 512)  2359808
['conv5_1[1][0]']


 conv5_3 (Conv2D)               (None, 14, 14, 512)  2359808
['conv5_2[1][0]']


 gaussian_noise_2 (GaussianNois  (None, 14, 14, 512)  0
['conv5_3[1][0]']
 e)



 pool5 (MaxPooling2D)           (None, 7, 7, 512)    0
['gaussian_noise_2[0][0]']
```

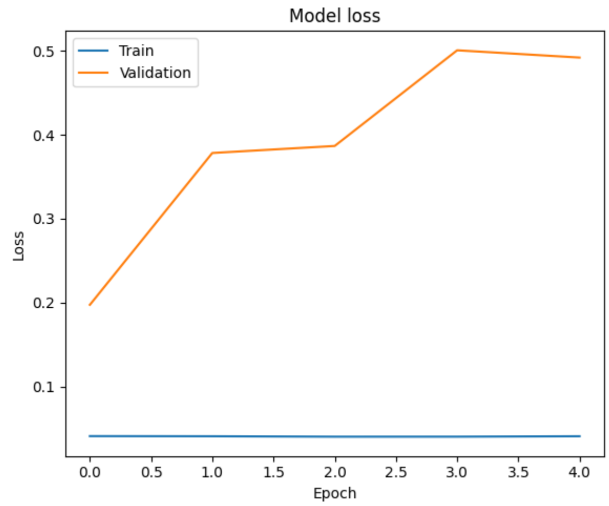
```
 global_average_pooling2d (Glob  (None, 512)         0
['pool5[1][0]']
 alAveragePooling2D)



 flatten (Flatten)              (None, 512)         0
['global_average_pooling2d[1][0]'
                                                                 ]



 dense (Dense)                  (None, 1)           513
['flatten[1][0]']


======================================================================
============================
Total params: 14,715,201
Trainable params: 14,715,201
Non-trainable params: 0
______________________________________________________________________
____________________________
```

```
# Train the noisy model on bad data for layers conv4_3 to conv5_3
from tensorflow.keras.callbacks import ModelCheckpoint, EarlyStopping
# Set up callbacks
checkpoint = ModelCheckpoint('noise_model.h5', save_best_only=True,
monitor='val_loss', mode='min')
early_stop = EarlyStopping(monitor='val_loss', patience=10,
restore_best_weights=True)

history_noise = noise_face_model.fit(X_train_deficit, y_train_deficit,
validation_split=0.2, epochs=5, batch_size=32, callbacks=[checkpoint,
early_stop])
```

```
Epoch 1/5
239/239 [==============================] - 63s 263ms/step - loss:
0.0408 - accuracy: 0.9934 - val_loss: 0.1974 - val_accuracy: 0.9921
Epoch 2/5
239/239 [==============================] - 62s 261ms/step - loss:
0.0407 - accuracy: 0.9934 - val_loss: 0.3783 - val_accuracy: 0.9921
Epoch 3/5
239/239 [==============================] - 62s 261ms/step - loss:
0.0402 - accuracy: 0.9934 - val_loss: 0.3867 - val_accuracy: 0.9921
Epoch 4/5
239/239 [==============================] - 62s 261ms/step - loss:
0.0402 - accuracy: 0.9934 - val_loss: 0.5008 - val_accuracy: 0.9921
Epoch 5/5
```

```
239/239 [==============================] - 62s 261ms/step - loss: 0.0407 - accuracy: 0.9934 - val_loss: 0.4921 - val_accuracy: 0.9921

plot_model_metrics(history_noise)
```






```python
import numpy as np
from tensorflow.keras.backend import clear_session

def calculate_accuracy(rebuild_model_func, rebuild_model_args, test_images, test_labels, threshold=0.5, num_runs=5):
    """
    Evaluate the model over a number of runs and return the average accuracy.

    :param rebuild_model_func: Function to rebuild the model.
    :param rebuild_model_args: Positional arguments for the rebuild model function.
    :param rebuild_model_kwargs: Keyword arguments for the rebuild model function.
    :param test_images: Array of test images.
    :param test_labels: Array of true labels for the test images.
    :param threshold: Threshold to convert predicted probabilities to binary predictions.
    :param num_runs: Number of runs to perform.
    :return: Average accuracy over the specified number of runs.
    """
    total_accuracy = 0

    # Perform training and evaluation in a loop
    for run in range(num_runs):
        # Reset the session
        clear_session()
        face_model = build_model()
```

```
        # Rebuild the model with the provided function and arguments
        model = add_noise_to_specific_layers(face_model, noisy_layers, 
noise_level=0.8)

        # Compile the model
        model.compile(optimizer='adam', loss='binary_crossentropy', 
metrics=['accuracy'])

        # Make predictions using the model
        predictions = model.predict(test_images)

        # Convert predictions to binary using the defined threshold
        binary_predictions = (predictions > 
threshold).astype(int).flatten()

        # Calculate accuracy
        num_correct = np.sum(binary_predictions == test_labels)
        accuracy = num_correct / len(test_labels)

        # Accumulate total accuracy
        total_accuracy += accuracy
        print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

    # Calculate the average accuracy over all runs
    avg_accuracy = total_accuracy / num_runs
    print(f"Average Accuracy over {num_runs} runs: {avg_accuracy * 
100:.2f}%")
    return avg_accuracy, binary_predictions
```

Noise Model [GRAD CAM Layers]

Normal

```
accuracy, binary_predictions_normal = 
calculate_accuracy(rebuild_model_func=add_noise_to_specific_layers, 

rebuild_model_args=(face_model, noisy_layers, 0.8),
                                                  test_images=X_test, 
                                                  test_labels=y_test)
```

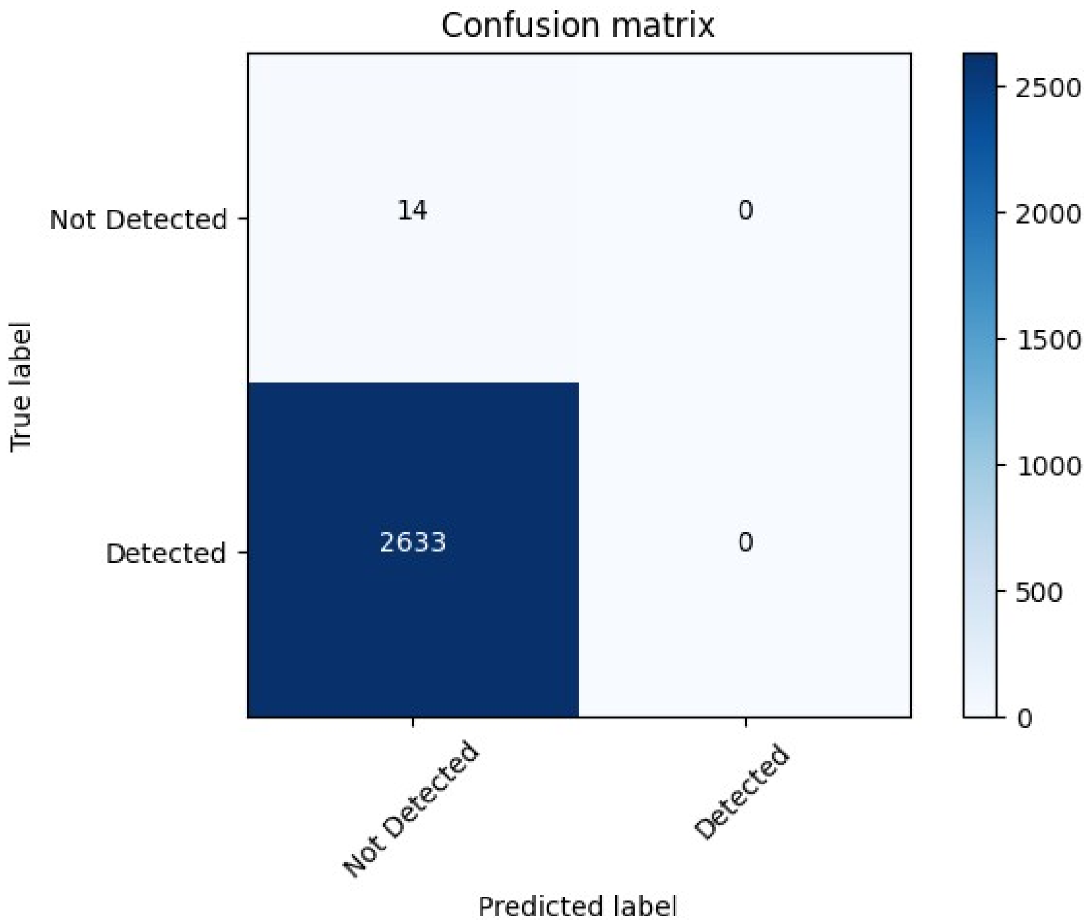
```
WARNING:tensorflow:Functional model inputs must come from 
`tf.keras.Input` (thus holding past layer metadata). They cannot be 
the output of a previous non-Input layer. Here, a tensor specified as 
input to "model_1" was not an Input tensor, it was generated by layer 
"input_1".
Note that input tensors are instantiated via `tensor = 
tf.keras.Input(shape)`.
The tensor that caused the issue was: 
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
```

```
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 98ms/step
Run 1: Accuracy = 13.22%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 97ms/step
Run 2: Accuracy = 86.48%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 3: Accuracy = 22.40%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 4: Accuracy = 67.17%
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 95ms/step
Run 5: Accuracy = 0.53%
Average Accuracy over 5 runs: 37.96%
```

```
# performace on normal data
y_true = y_test
y_pred = binary_predictions_normal

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0
Recall: 0.0
F1 Score: 0
```



Eyebrows

```
clear_session()
face_model = build_model()
accuracy, binary_predictions_brows = 
calculate_accuracy(rebuild_model_func=add_noise_to_specific_layers,

rebuild_model_args=(face_model, noisy_layers, 0.8),

test_images=X_test_brows,

test_labels=y_test_brows)
```

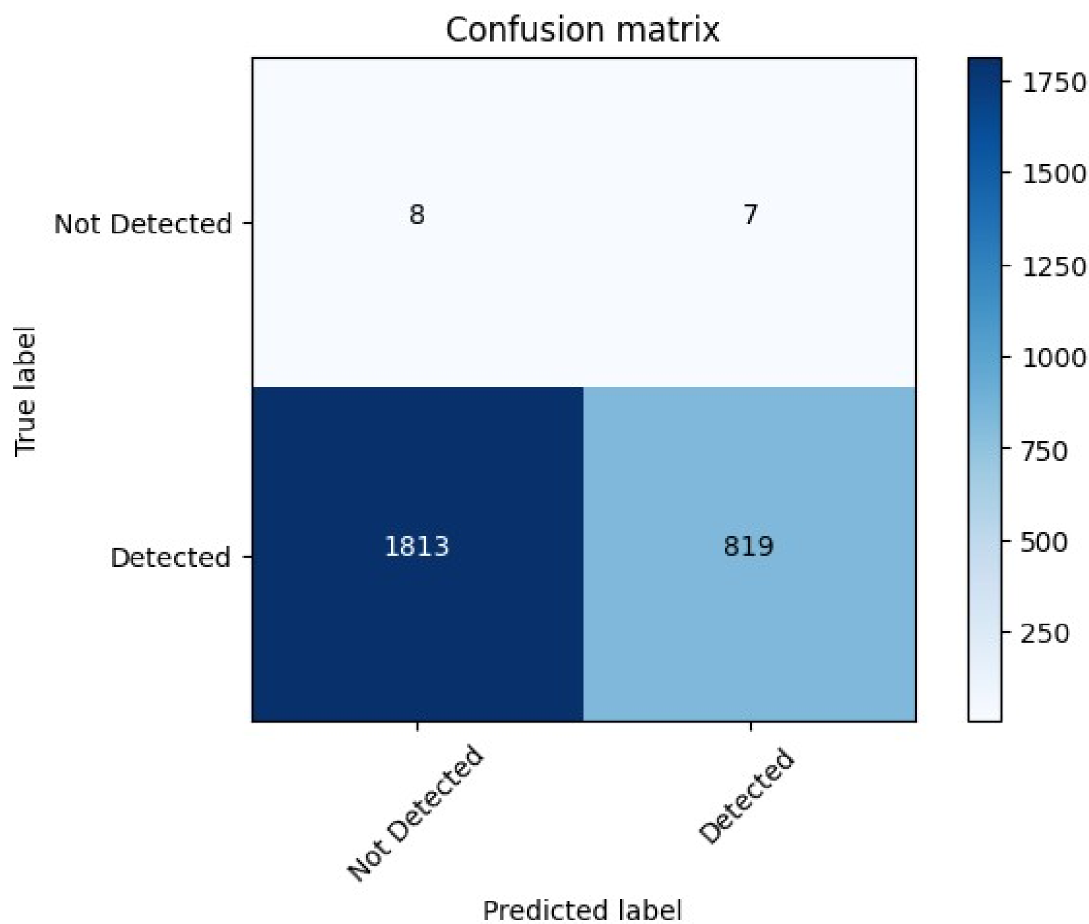
```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
```

```
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 1: Accuracy = 31.24%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 97ms/step
Run 2: Accuracy = 31.24%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 97ms/step
Run 3: Accuracy = 31.24%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 4: Accuracy = 31.24%
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 5: Accuracy = 31.24%
Average Accuracy over 5 runs: 31.24%
```

```
# performace on normal data
y_true = y_test_brows
y_pred = binary_predictions_brows

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9915254237288136
Recall: 0.31117021276595747
F1 Score: 0.4736842105263159
```



Eyes

```
clear_session()
face_model = build_model()
accuracy, binary_predictions_eyes =
calculate_accuracy(rebuild_model_func=add_noise_to_specific_layers,

rebuild_model_args=(face_model, noisy_layers, 0.8),

test_images=X_test_eyes,

test_labels=y_test_eyes)
```

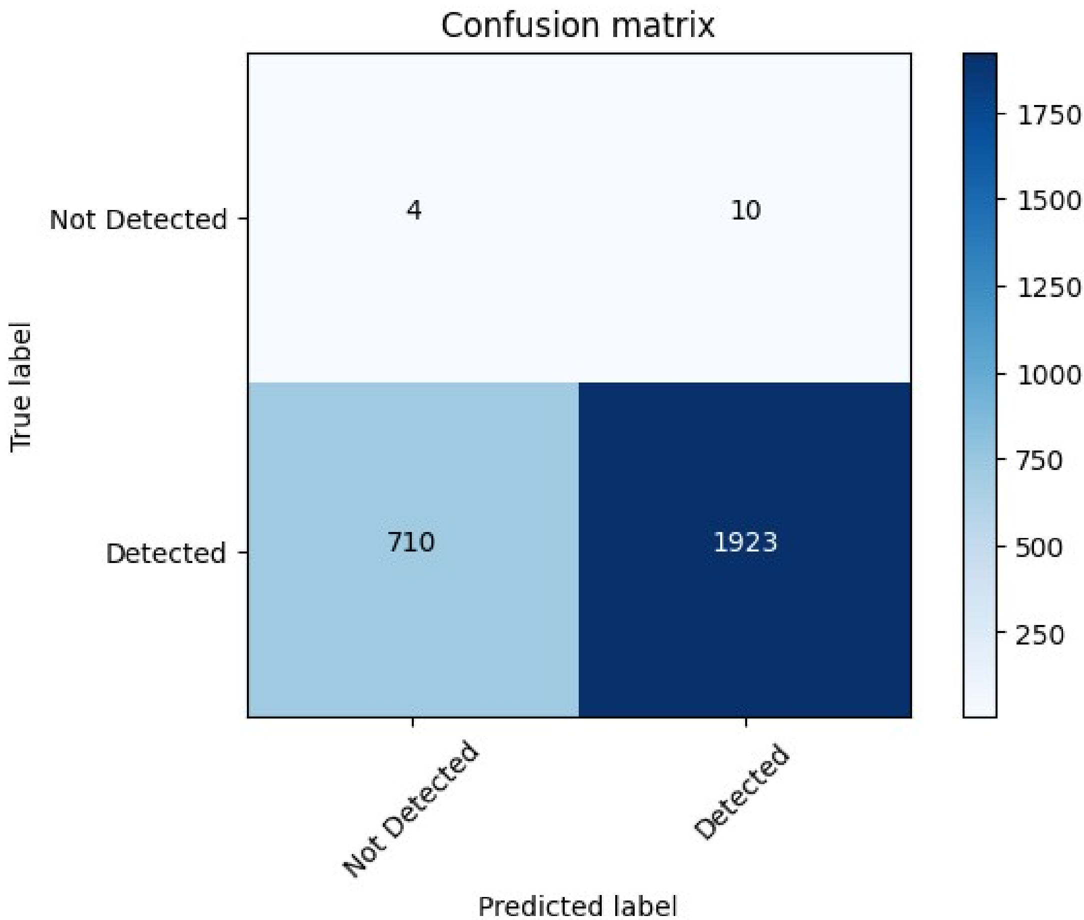
```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
```

```
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 95ms/step
Run 1: Accuracy = 72.80%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 97ms/step
Run 2: Accuracy = 72.80%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 97ms/step
Run 3: Accuracy = 72.80%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 4: Accuracy = 72.80%
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 5: Accuracy = 72.80%
Average Accuracy over 5 runs: 72.80%
```

```
# performace on normal data
y_true = y_test_eyes
y_pred = binary_predictions_eyes

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9948266942576306
Recall: 0.7303456133687809
F1 Score: 0.8423127463863338
```



Nose

```
clear_session()
# face_model = build_model()
accuracy, binary_predictions_noise = 
calculate_accuracy(rebuild_model_func=add_noise_to_specific_layers,

rebuild_model_args=(face_model, noisy_layers, 0.8),

test_images=X_test_nose,

test_labels=y_test_nose)
```

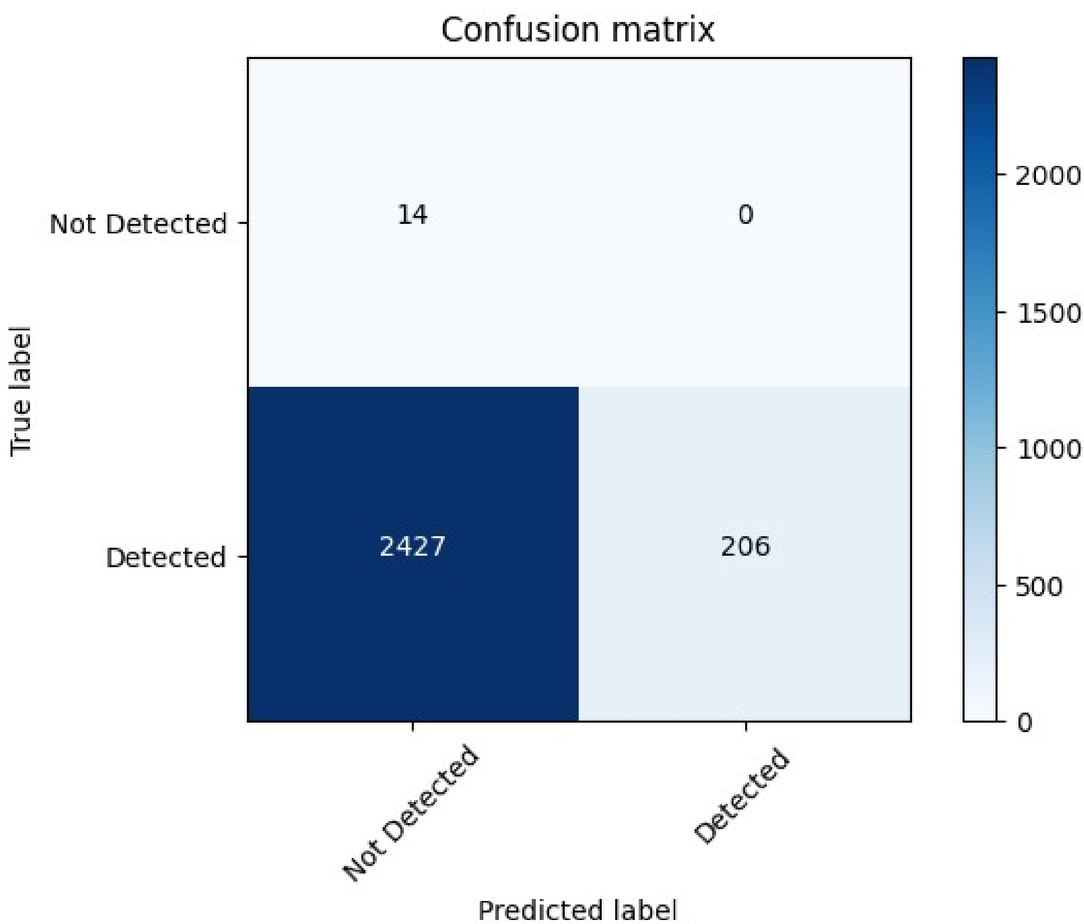
```
WARNING:tensorflow:Functional model inputs must come from 
`tf.keras.Input` (thus holding past layer metadata). They cannot be 
the output of a previous non-Input layer. Here, a tensor specified as 
input to "model" was not an Input tensor, it was generated by layer 
"input_1".
Note that input tensors are instantiated via `tensor = 
tf.keras.Input(shape)`.
The tensor that caused the issue was: 
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
```

```
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 97ms/step
Run 1: Accuracy = 73.55%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 98ms/step
Run 2: Accuracy = 73.55%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 97ms/step
Run 3: Accuracy = 73.55%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 4: Accuracy = 73.55%
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 95ms/step
Run 5: Accuracy = 73.55%
Average Accuracy over 5 runs: 73.55%
```

```python
# performace on normal data
y_true = y_test_nose
y_pred = binary_predictions_nose

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 1.0
Recall: 0.07823775161412837
F1 Score: 0.14512152166255723
```



Mouth

```
clear_session()
# face_model = build_model()
accuracy, binary_predictions_noise =
calculate_accuracy(rebuild_model_func=add_noise_to_specific_layers,

rebuild_model_args=(face_model, noisy_layers, 0.8),

test_images=X_test_nose,

test_labels=y_test_nose)

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
```

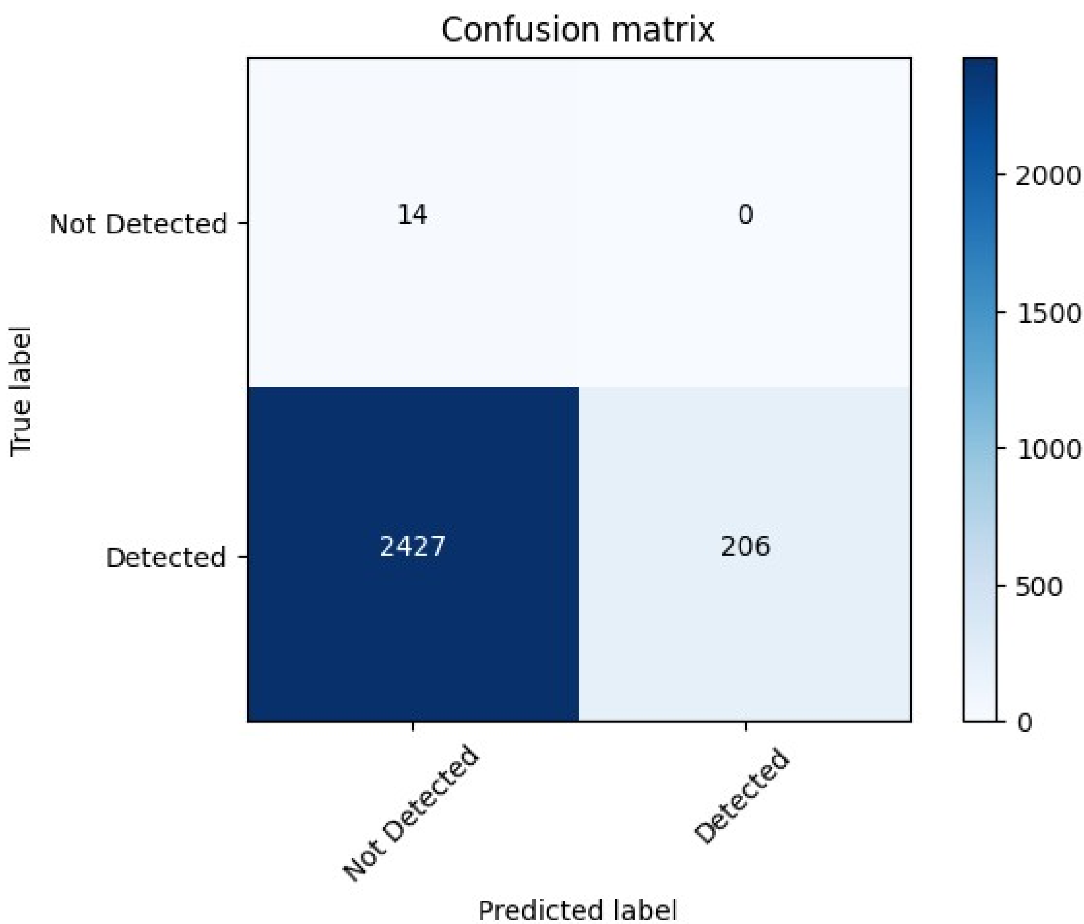
```
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 93ms/step
Run 1: Accuracy = 13.07%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 93ms/step
Run 2: Accuracy = 48.92%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 94ms/step
Run 3: Accuracy = 82.32%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 94ms/step
Run 4: Accuracy = 44.35%
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")
```

```
83/83 [==============================] - 8s 96ms/step
Run 5: Accuracy = 87.68%
Average Accuracy over 5 runs: 55.27%
```

```
# performace on normal data
y_true = y_test_nose
y_pred = binary_predictions_nose

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 1.0
Recall: 0.07823775161412837
F1 Score: 0.14512152166255723
```



Approach 3: Selective Dropout

```
from keras.models import clone_model
from keras.layers import Dropout

def add_selective_dropout(base_model, dropout_layers,
dropout_rate=0.5):
    """
    Adds dropout to specific layers without modifying the base model.

    :param base_model: The base Keras model.
    :param dropout_layers: A list of layer names where dropout should
be added.
    :param dropout_rate: The dropout rate.
    :return: A new model with selective dropout.
    """
    # Clone the base model
    model_clone = clone_model(base_model)
    model_clone.set_weights(base_model.get_weights())

    # Rebuild model architecture and add dropout to the specified
```

```
layers
    x = model_clone.input
    for layer in model_clone.layers:
        if layer.name in dropout_layers:
            # Add dropout after the specified layer
            x = Dropout(dropout_rate)(layer(x))
        else:
            x = layer(x)

    # Create the new model with selective dropout
    model_with_dropout = Model(inputs=model_clone.input, outputs=x)
    # Compile the new model as needed
    model_with_dropout.compile(optimizer='adam',
loss='binary_crossentropy', metrics=['accuracy'])
    return model_with_dropout

clear_session()
face_model = build_model()
# Specify the layers to be ablated based on Grad-CAM results
dropout_layers = ['conv4_3', 'conv5_1', 'conv5_2', 'conv5_3']

# Build the model with feature ablation
dropout_face_model = add_selective_dropout(face_model, dropout_layers,
dropout_rate=0.8)


# Display the summary to confirm the ablation layers are included
dropout_face_model.summary()
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

Model: "model_1"
______________________________________________________________________
____________________________
 Layer (type)                Output Shape         Param #
Connected to
======================================================================
============================
 input_1 (InputLayer)        multiple             0
['input_1[0][0]']
```

```
 conv1_1 (Conv2D)                (None, 224, 224, 64  1792
['input_1[1][0]']
                                )

 conv1_2 (Conv2D)                (None, 224, 224, 64  36928
['conv1_1[1][0]']
                                )

 pool1 (MaxPooling2D)            (None, 112, 112, 64  0
['conv1_2[1][0]']
                                )

 conv2_1 (Conv2D)                (None, 112, 112, 12  73856
['pool1[1][0]']
                                8)

 conv2_2 (Conv2D)                (None, 112, 112, 12  147584
['conv2_1[1][0]']
                                8)

 pool2 (MaxPooling2D)            (None, 56, 56, 128)  0
['conv2_2[1][0]']

 conv3_1 (Conv2D)                (None, 56, 56, 256)  295168
['pool2[1][0]']

 conv3_2 (Conv2D)                (None, 56, 56, 256)  590080
['conv3_1[1][0]']

 conv3_3 (Conv2D)                (None, 56, 56, 256)  590080
['conv3_2[1][0]']

 pool3 (MaxPooling2D)            (None, 28, 28, 256)  0
['conv3_3[1][0]']
```

```
 conv4_1 (Conv2D)               (None, 28, 28, 512)  1180160
['pool3[1][0]']


 conv4_2 (Conv2D)               (None, 28, 28, 512)  2359808
['conv4_1[1][0]']


 conv4_3 (Conv2D)               (None, 28, 28, 512)  2359808
['conv4_2[1][0]']


 dropout (Dropout)              (None, 28, 28, 512)  0
['conv4_3[1][0]']


 pool4 (MaxPooling2D)           (None, 14, 14, 512)  0
['dropout[0][0]']


 conv5_1 (Conv2D)               (None, 14, 14, 512)  2359808
['pool4[1][0]']


 dropout_1 (Dropout)            (None, 14, 14, 512)  0
['conv5_1[1][0]']


 conv5_2 (Conv2D)               (None, 14, 14, 512)  2359808
['dropout_1[0][0]']


 dropout_2 (Dropout)            (None, 14, 14, 512)  0
['conv5_2[1][0]']


 conv5_3 (Conv2D)               (None, 14, 14, 512)  2359808
['dropout_2[0][0]']


 dropout_3 (Dropout)            (None, 14, 14, 512)  0
['conv5_3[1][0]']


 pool5 (MaxPooling2D)           (None, 7, 7, 512)    0
['dropout_3[0][0]']


 global_average_pooling2d (Glob  (None, 512)         0
```

```
['pool5[1][0]']
 alAveragePooling2D)



 flatten (Flatten)              (None, 512)         0
['global_average_pooling2d[1][0]'
                                                                   ]



 dense (Dense)                  (None, 1)           513
['flatten[1][0]']


======================================================================
============================
Total params: 14,715,201
Trainable params: 14,715,201
Non-trainable params: 0
______________________________________________________________________
____________________________
```

```python
import numpy as np
from tensorflow.keras.backend import clear_session

def calculate_accuracy(test_images, test_labels, threshold=0.5,
num_runs=5):
    """
    Evaluate the model over a number of runs and return the average
accuracy.

    :param rebuild_model_func: Function to rebuild the model.
    :param rebuild_model_args: Positional arguments for the rebuild
model function.
    :param rebuild_model_kwargs: Keyword arguments for the rebuild
model function.
    :param test_images: Array of test images.
    :param test_labels: Array of true labels for the test images.
    :param threshold: Threshold to convert predicted probabilities to
binary predictions.
    :param num_runs: Number of runs to perform.
    :return: Average accuracy over the specified number of runs.
    """
    total_accuracy = 0

    # Perform training and evaluation in a loop
    for run in range(num_runs):

        # Reset the session
```

```
        clear_session()
        face_model = build_model()
        # Rebuild the model with the provided function and arguments
        model = add_selective_dropout(face_model, dropout_layers, 
dropout_rate=0.8)

        # Compile the model
        model.compile(optimizer='adam', loss='binary_crossentropy', 
metrics=['accuracy'])

        # Make predictions using the model
        predictions = model.predict(test_images)

        # Convert predictions to binary using the defined threshold
        binary_predictions = (predictions > 
threshold).astype(int).flatten()

        # Calculate accuracy
        num_correct = np.sum(binary_predictions == test_labels)
        accuracy = num_correct / len(test_labels)

        # Accumulate total accuracy
        total_accuracy += accuracy
        print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

    # Calculate the average accuracy over all runs
    avg_accuracy = total_accuracy / num_runs
    print(f"Average Accuracy over {num_runs} runs: {avg_accuracy * 
100:.2f}%")
    return avg_accuracy, binary_predictions
```

Normal

```
_, binary_predictions_normal = calculate_accuracy(X_test, y_test, 
threshold=0.5, num_runs=5)
```

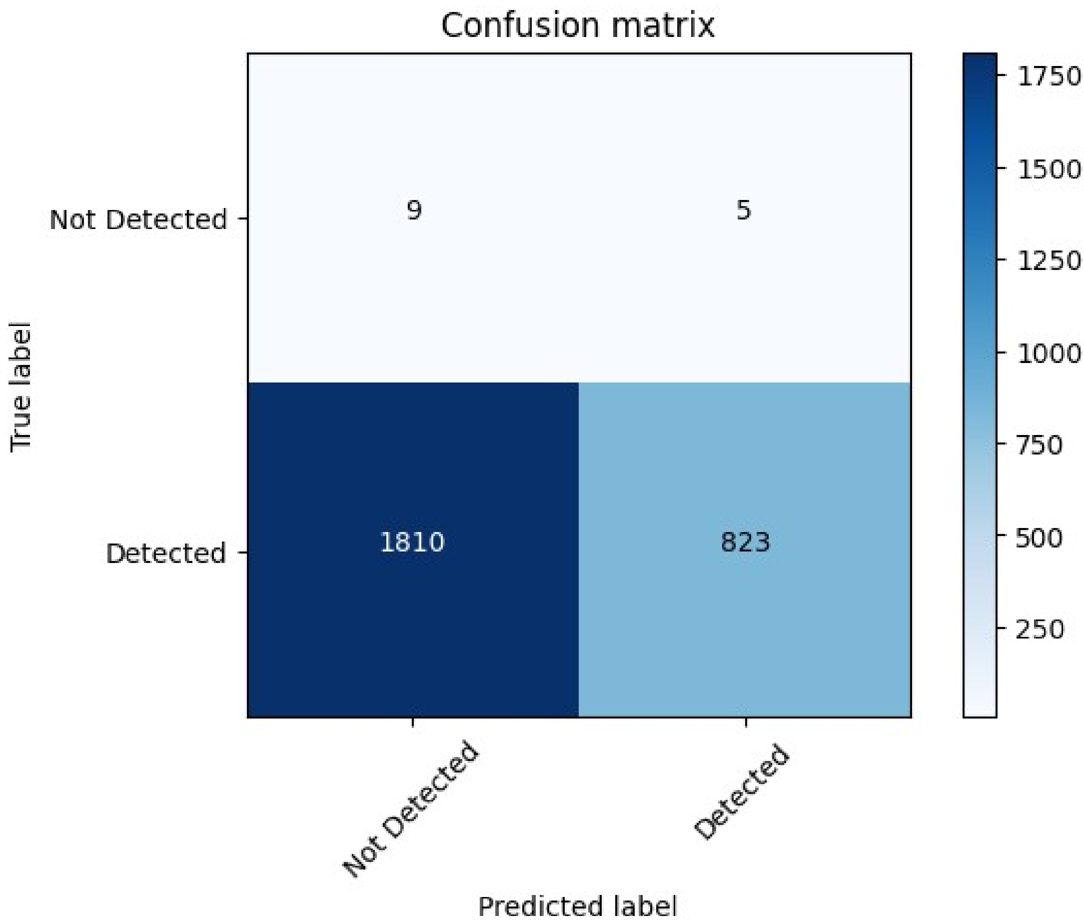
```
WARNING:tensorflow:Functional model inputs must come from 
`tf.keras.Input` (thus holding past layer metadata). They cannot be 
the output of a previous non-Input layer. Here, a tensor specified as 
input to "model_1" was not an Input tensor, it was generated by layer 
"input_1".
Note that input tensors are instantiated via `tensor = 
tf.keras.Input(shape)`.
The tensor that caused the issue was: 
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3), 
dtype=tf.float32, name='input_1'), name='input_1', 
description="created by layer 'input_1'")

83/83 [==============================] - 8s 93ms/step
Run 1: Accuracy = 26.60%
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 93ms/step
Run 2: Accuracy = 5.93%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 92ms/step
Run 3: Accuracy = 96.94%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 92ms/step
Run 4: Accuracy = 73.82%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
```

```
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 93ms/step
Run 5: Accuracy = 31.43%
Average Accuracy over 5 runs: 46.94%
```

```
# performace on normal data
y_true = y_test
y_pred = binary_predictions_normal

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9939613526570048
Recall: 0.3125712115457653
F1 Score: 0.4755850910141578
```



Eyebrows

```
_, binary_predictions_brows = calculate_accuracy(X_test_brows,
y_test_brows, threshold=0.5, num_runs=5)
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 94ms/step
Run 1: Accuracy = 20.36%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
```

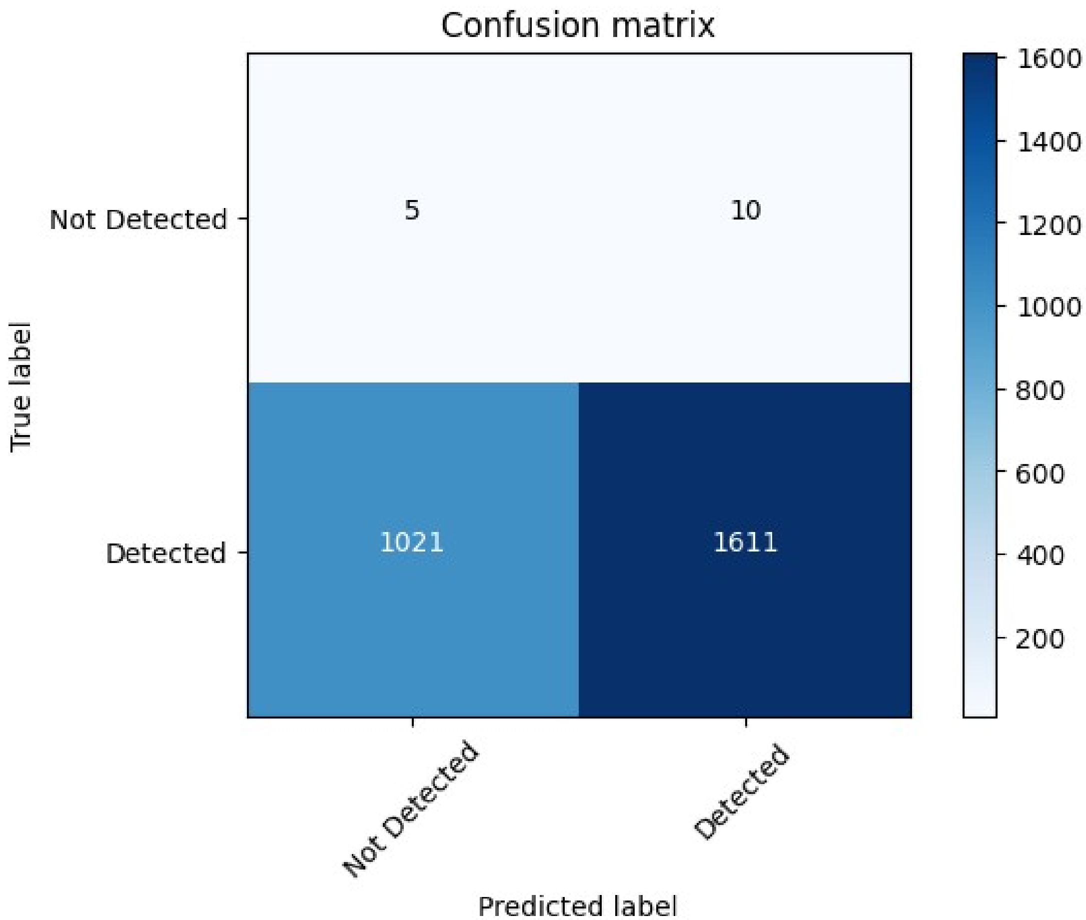
```
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 95ms/step
Run 2: Accuracy = 52.81%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 94ms/step
Run 3: Accuracy = 45.83%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 95ms/step
Run 4: Accuracy = 3.40%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
```

```
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")
```

```
83/83 [==============================] - 8s 96ms/step
Run 5: Accuracy = 61.05%
Average Accuracy over 5 runs: 36.69%
```

```
# performace on normal data
y_true = y_test_brows
y_pred = binary_predictions_brows

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.99383096853793 95
Recall: 0.6120820668693009
F1 Score: 0.7575828826710557
```



Eyes

```
_, binary_predictions_eyes = calculate_accuracy(X_test_eyes,
y_test_eyes, threshold=0.5, num_runs=5)
```

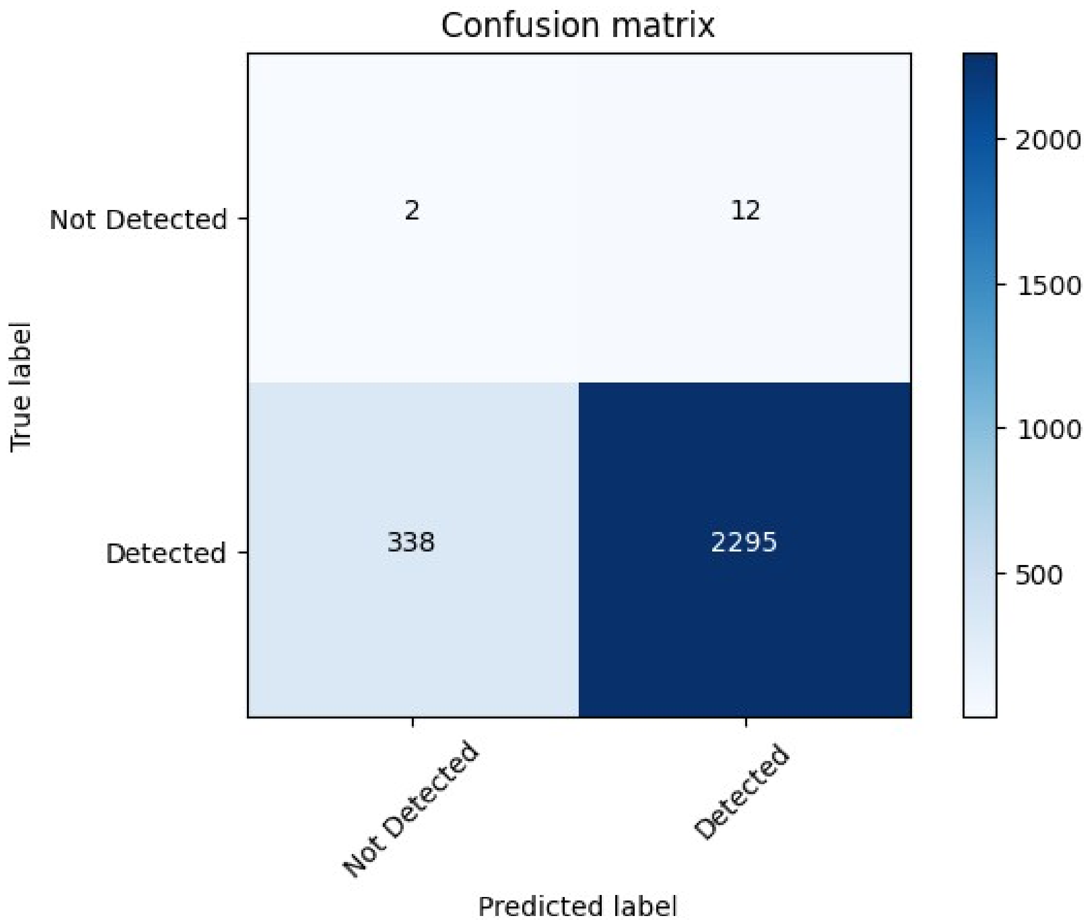
```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 91ms/step
Run 1: Accuracy = 63.47%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
```

```
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 92ms/step
Run 2: Accuracy = 72.46%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 92ms/step
Run 3: Accuracy = 15.04%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 93ms/step
Run 4: Accuracy = 63.47%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
```

```
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 93ms/step
Run 5: Accuracy = 86.78%
Average Accuracy over 5 runs: 60.24%
```

```python
# performace on normal data
y_true = y_test_eyes
y_pred = binary_predictions_eyes

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9947984395318595
Recall: 0.8716293201671098
F1 Score: 0.9291497975708503
```



Nose

```
_, binary_predictions_nose = calculate_accuracy(X_test_nose,
y_test_nose, threshold=0.5, num_runs=5)
```

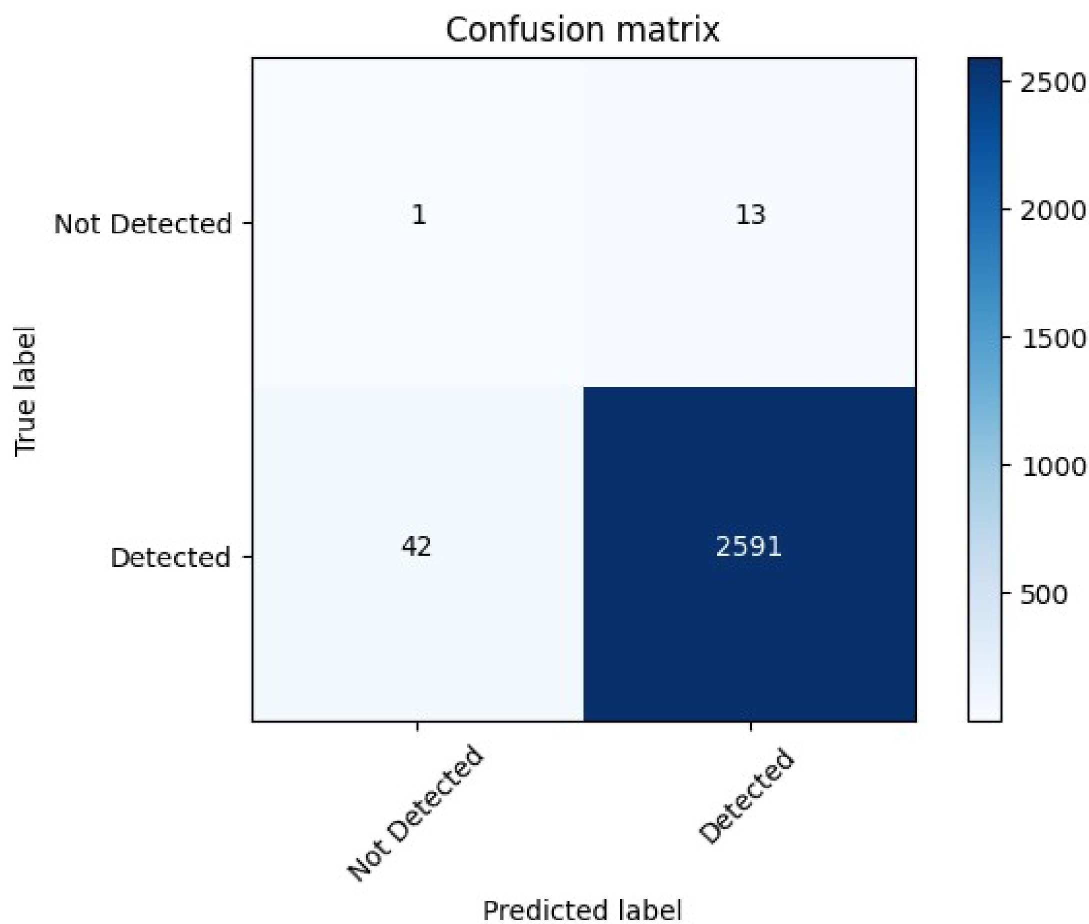
```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 94ms/step
Run 1: Accuracy = 94.79%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
```

```
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 95ms/step
Run 2: Accuracy = 92.82%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 3: Accuracy = 2.53%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 4: Accuracy = 40.01%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
```

```
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 5: Accuracy = 97.92%
Average Accuracy over 5 runs: 65.61%
```

```
# performace on normal data
y_true = y_test_nose
y_pred = binary_predictions_nose

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9950076804915514
Recall: 0.9840486137485758
F1 Score: 0.9894978040863089
```



Mouth

```
_, binary_predictions_mouth = calculate_accuracy(X_test_mouth,
y_test_mouth, threshold=0.5, num_runs=5)

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 93ms/step
Run 1: Accuracy = 21.57%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
```

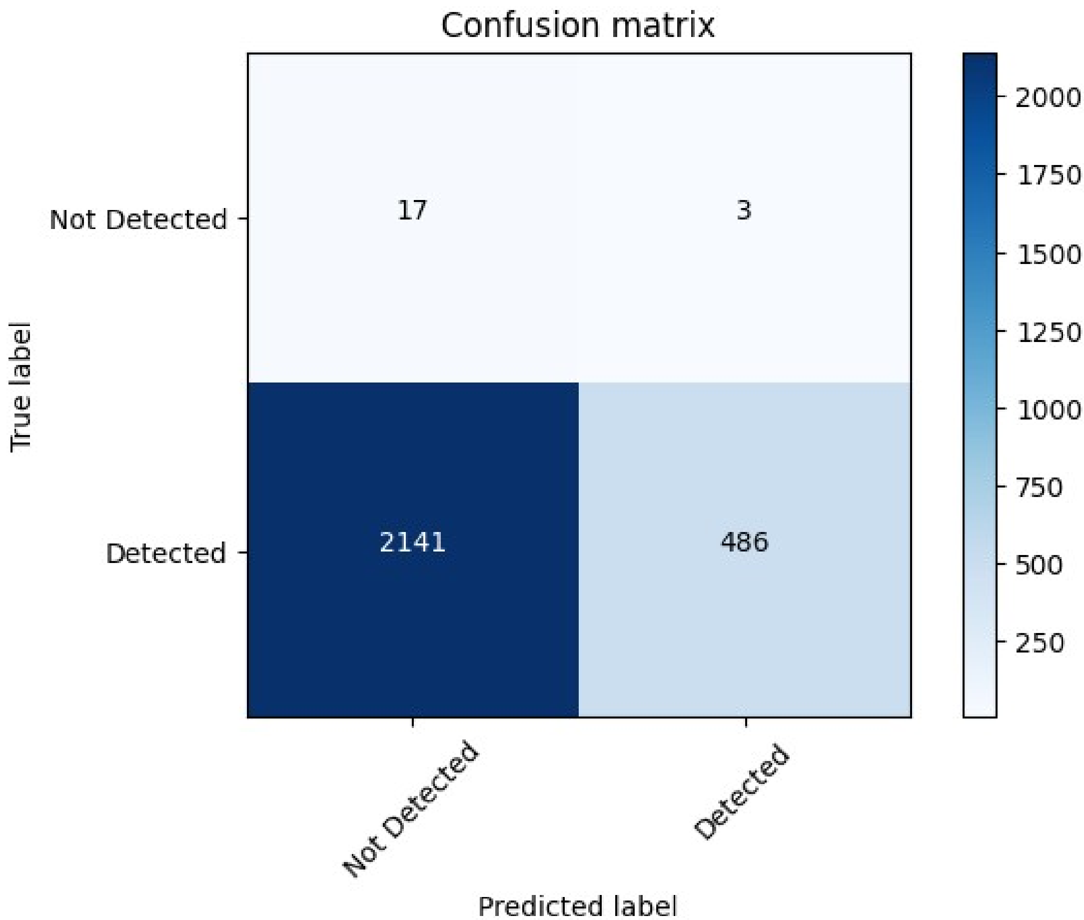
```
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 94ms/step
Run 2: Accuracy = 5.67%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 95ms/step
Run 3: Accuracy = 94.45%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

83/83 [==============================] - 8s 96ms/step
Run 4: Accuracy = 59.88%

WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
```

```
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")
```

```
83/83 [==============================] - 8s 97ms/step
Run 5: Accuracy = 19.00%
Average Accuracy over 5 runs: 40.11%
```

```
# performace on normal data
y_true = y_test_mouth
y_pred = binary_predictions_mouth

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9938650306748467
Recall: 0.18500190331176247
F1 Score: 0.3119383825417202
```



Approach 4: Combine dropout, ablation, and noise

```
clear_session()
# Specify the layers to be ablated based on Grad-CAM results
layers = ['conv3_2', 'conv4_3', 'conv5_3']

# Add feature ablation
ablation = build_model_with_ablation(layers)
# Add noise
noise = add_noise_to_specific_layers(ablation, noisy_layers,
noise_level=0.8)
# Add dropout
dropout = add_selective_dropout(noise , dropout_layers,
dropout_rate=0.8)
dropout.compile(optimizer='adam', loss='categorical_crossentropy',
metrics=['accuracy'])
dropout.summary()
```

```
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_1" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")
WARNING:tensorflow:Functional model inputs must come from
`tf.keras.Input` (thus holding past layer metadata). They cannot be
the output of a previous non-Input layer. Here, a tensor specified as
input to "model_2" was not an Input tensor, it was generated by layer
"input_1".
Note that input tensors are instantiated via `tensor =
```

```
tf.keras.Input(shape)`.
The tensor that caused the issue was:
KerasTensor(type_spec=TensorSpec(shape=(None, 224, 224, 3),
dtype=tf.float32, name='input_1'), name='input_1',
description="created by layer 'input_1'")

Model: "model_2"
_________________________________________________________________________
_____________________________
 Layer (type)                    Output Shape         Param #
Connected to
=========================================================================
=============================
 input_1 (InputLayer)            multiple             0
['input_1[0][0]']


 ablated_input_1 (Lambda)        (None, 224, 224, 3)  0
['input_1[2][0]']


 conv1_1 (Conv2D)                (None, 224, 224, 64  1792
['ablated_input_1[1][0]']
                                 )



 ablated_conv1_1 (Lambda)        (None, 224, 224, 64  0
['conv1_1[1][0]']
                                 )



 conv1_2 (Conv2D)                (None, 224, 224, 64  36928
['ablated_conv1_1[1][0]']
                                 )



 ablated_conv1_2 (Lambda)        (None, 224, 224, 64  0
['conv1_2[1][0]']
                                 )



 pool1 (MaxPooling2D)            (None, 112, 112, 64  0
['ablated_conv1_2[1][0]']
                                 )
```

```
 ablated_pool1 (Lambda)         (None, 112, 112, 64  0
['pool1[1][0]']
                                )


 conv2_1 (Conv2D)               (None, 112, 112, 12  73856
['ablated_pool1[1][0]']
                                8)


 ablated_conv2_1 (Lambda)       (None, 112, 112, 12  0
['conv2_1[1][0]']
                                8)


 conv2_2 (Conv2D)               (None, 112, 112, 12  147584
['ablated_conv2_1[1][0]']
                                8)


 ablated_conv2_2 (Lambda)       (None, 112, 112, 12  0
['conv2_2[1][0]']
                                8)


 pool2 (MaxPooling2D)           (None, 56, 56, 128)  0
['ablated_conv2_2[1][0]']

 ablated_pool2 (Lambda)         (None, 56, 56, 128)  0
['pool2[1][0]']

 conv3_1 (Conv2D)               (None, 56, 56, 256)  295168
['ablated_pool2[1][0]']

 ablated_conv3_1 (Lambda)       (None, 56, 56, 256)  0
['conv3_1[1][0]']

 conv3_2 (Conv2D)               (None, 56, 56, 256)  590080
['ablated_conv3_1[1][0]']

 gaussian_noise (GaussianNoise)  (None, 56, 56, 256)  0
```

```
['conv3_2[1][0]']


 ablated_conv3_2 (Lambda)       (None, 56, 56, 256)  0
['gaussian_noise[1][0]']


 conv3_3 (Conv2D)               (None, 56, 56, 256)  590080
['ablated_conv3_2[1][0]']


 ablated_conv3_3 (Lambda)       (None, 56, 56, 256)  0
['conv3_3[1][0]']


 pool3 (MaxPooling2D)           (None, 28, 28, 256)  0
['ablated_conv3_3[1][0]']


 ablated_pool3 (Lambda)         (None, 28, 28, 256)  0
['pool3[1][0]']


 conv4_1 (Conv2D)               (None, 28, 28, 512)  1180160
['ablated_pool3[1][0]']


 ablated_conv4_1 (Lambda)       (None, 28, 28, 512)  0
['conv4_1[1][0]']


 conv4_2 (Conv2D)               (None, 28, 28, 512)  2359808
['ablated_conv4_1[1][0]']


 gaussian_noise_1 (GaussianNois  (None, 28, 28, 512)  0
['conv4_2[1][0]']
 e)



 ablated_conv4_2 (Lambda)       (None, 28, 28, 512)  0
['gaussian_noise_1[1][0]']


 conv4_3 (Conv2D)               (None, 28, 28, 512)  2359808
['ablated_conv4_2[1][0]']


 dropout (Dropout)              (None, 28, 28, 512)  0
```

```
['conv4_3[1][0]']


 ablated_conv4_3 (Lambda)       (None, 28, 28, 512)  0
['dropout[0][0]']


 pool4 (MaxPooling2D)           (None, 14, 14, 512)  0
['ablated_conv4_3[1][0]']


 ablated_pool4 (Lambda)         (None, 14, 14, 512)  0
['pool4[1][0]']


 conv5_1 (Conv2D)               (None, 14, 14, 512)  2359808
['ablated_pool4[1][0]']


 dropout_1 (Dropout)            (None, 14, 14, 512)  0
['conv5_1[1][0]']


 ablated_conv5_1 (Lambda)       (None, 14, 14, 512)  0
['dropout_1[0][0]']


 conv5_2 (Conv2D)               (None, 14, 14, 512)  2359808
['ablated_conv5_1[1][0]']


 dropout_2 (Dropout)            (None, 14, 14, 512)  0
['conv5_2[1][0]']


 ablated_conv5_2 (Lambda)       (None, 14, 14, 512)  0
['dropout_2[0][0]']


 conv5_3 (Conv2D)               (None, 14, 14, 512)  2359808
['ablated_conv5_2[1][0]']


 dropout_3 (Dropout)            (None, 14, 14, 512)  0
['conv5_3[1][0]']


 gaussian_noise_2 (GaussianNois  (None, 14, 14, 512)  0
['dropout_3[0][0]']
 e)
```

```
 ablated_conv5_3 (Lambda)       (None, 14, 14, 512)  0
['gaussian_noise_2[1][0]']


 pool5 (MaxPooling2D)           (None, 7, 7, 512)    0
['ablated_conv5_3[1][0]']


 ablated_pool5 (Lambda)         (None, 7, 7, 512)    0
['pool5[1][0]']


 global_average_pooling2d (Glob  (None, 512)         0
['ablated_pool5[1][0]']
 alAveragePooling2D)



 ablated_global_average_pooling  (None, 512)         0
['global_average_pooling2d[1][0]'
 2d (Lambda)                                                        ]



 flatten (Flatten)              (None, 512)          0
['ablated_global_average_pooling2
                                                                    d[1]
[0]']


 dense (Dense)                  (None, 1)            513
['flatten[1][0]']


======================================================================
============================
Total params: 14,715,201
Trainable params: 14,715,201
Non-trainable params: 0
______________________________________________________________________
____________________________
```

Normal

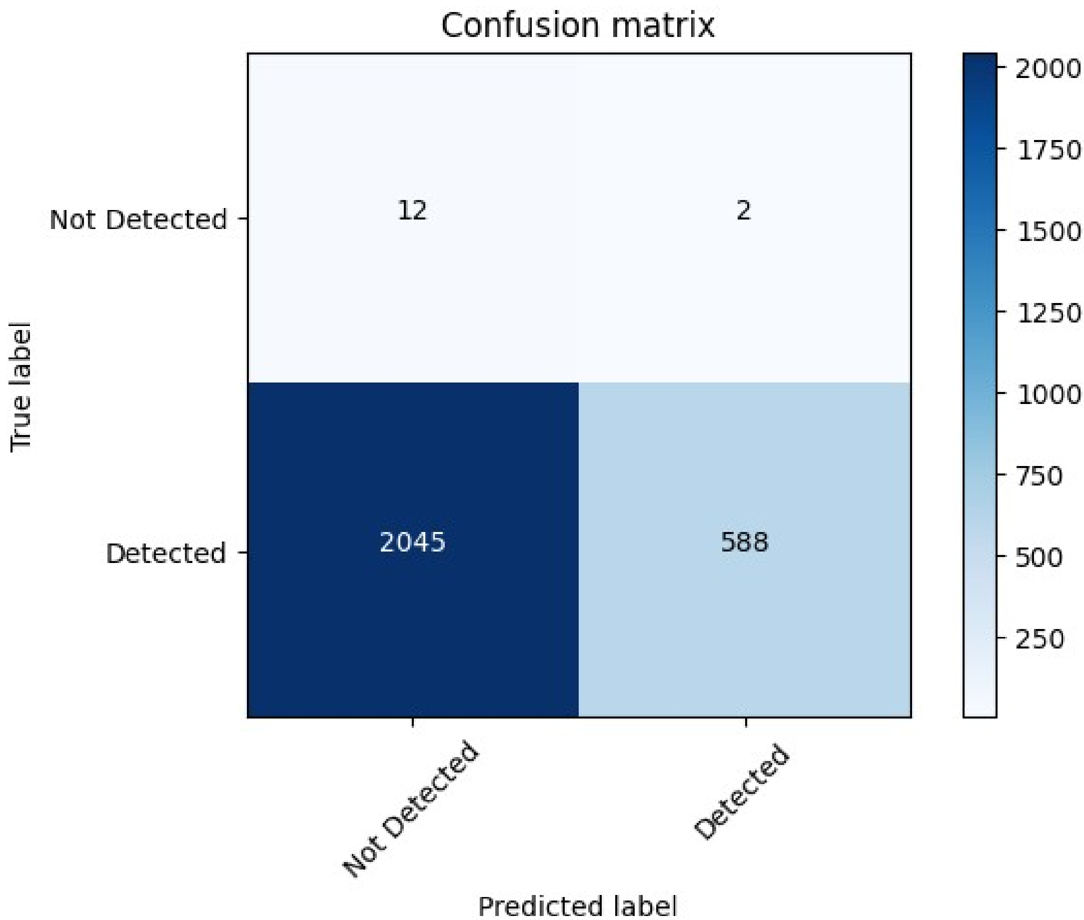
```
# Test the ablated model - normal data
# Load the test dataset
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here
```

```python
# Define a threshold for classifying as face detected
threshold = 0.5

# Make predictions using the model
# predictions = final_model.predict(test_images)
predictions = dropout.predict(test_images)
binary_predictions = (predictions.max(axis=1) > threshold).astype(int)

# Calculate accuracy
num_correct = 0
total_images = len(test_images)

for i in range(total_images):
    predicted_class = binary_predictions[i]
    true_class = test_labels[i]
    if predicted_class == true_class:
        num_correct += 1

accuracy = num_correct / total_images
print("Face model With feature ablation, noise injection, and
selective dropout [Layers: conv3_2, conv4_2, conv5_3]:", accuracy)
```

```
83/83 [==============================] - 8s 90ms/step
Face model With feature ablation, noise injection, and selective
dropout [Layers: conv3_2, conv4_2, conv5_3]: 0.22667170381564034
```

```python
# performace on normal data
y_true = y_test
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9966101694915255
Recall: 0.22331940751993923
F1 Score: 0.3648774433757369
```



Eyebrows

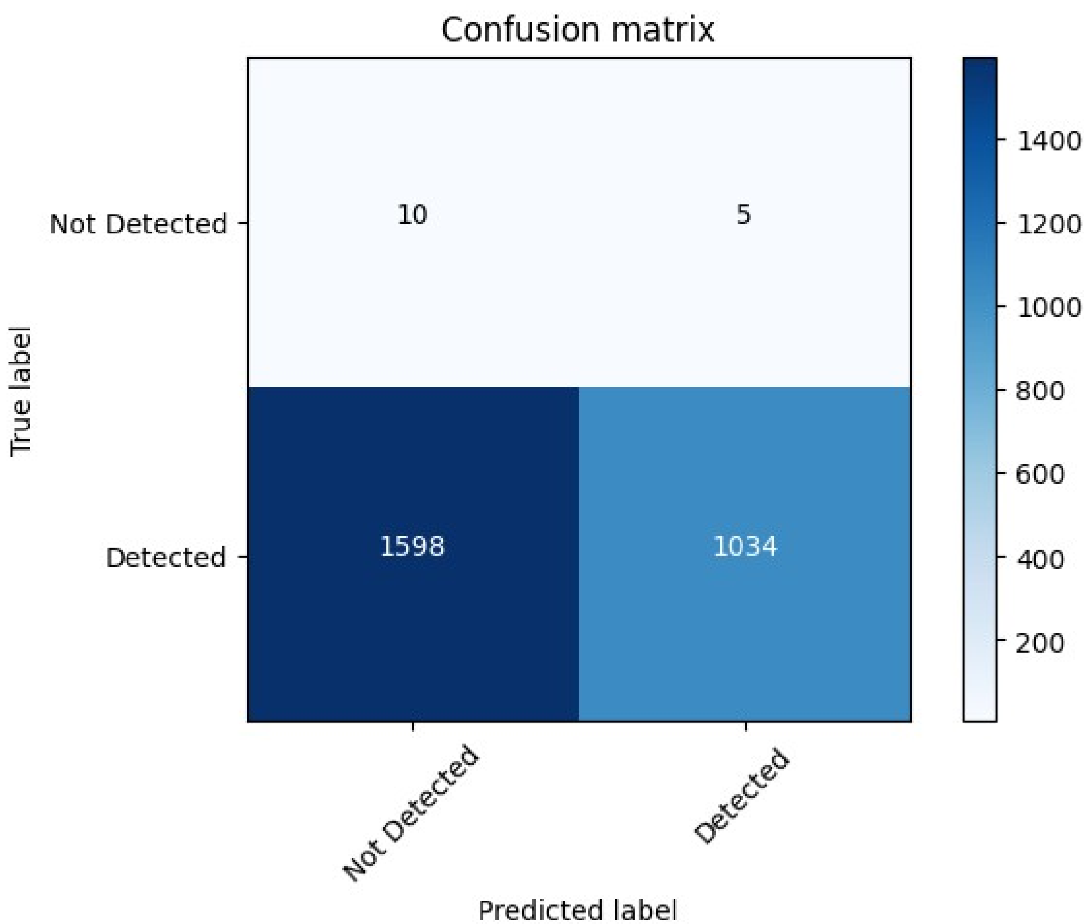
```
# Test the ablated model - normal data
# Load the test dataset
test_images = X_test_brows # Load your test images here
test_labels = y_test_brows # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

# Make predictions using the model
# predictions = final_model.predict(test_images)
predictions = dropout.predict(test_images)
binary_predictions = (predictions.max(axis=1) > threshold).astype(int)

# Calculate accuracy
num_correct = 0
total_images = len(test_images)

for i in range(total_images):
    predicted_class = binary_predictions[i]
    true_class = test_labels[i]
```

```
    if predicted_class == true_class:
        num_correct += 1

accuracy = num_correct / total_images
print("Face model With feature ablation, noise injection, and
selective dropout [Layers: conv3_2, conv4_2, conv5_3]:", accuracy)
```

```
83/83 [==============================] - 7s 90ms/step
Face model With feature ablation, noise injection, and selective
dropout [Layers: conv3_2, conv4_2, conv5_3]: 0.3944087646392142
```

```
# performace on normal data
y_true = test_labels
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9951876804619827
Recall: 0.39285714285714285
F1 Score: 0.5633342413511305
```



Eyes

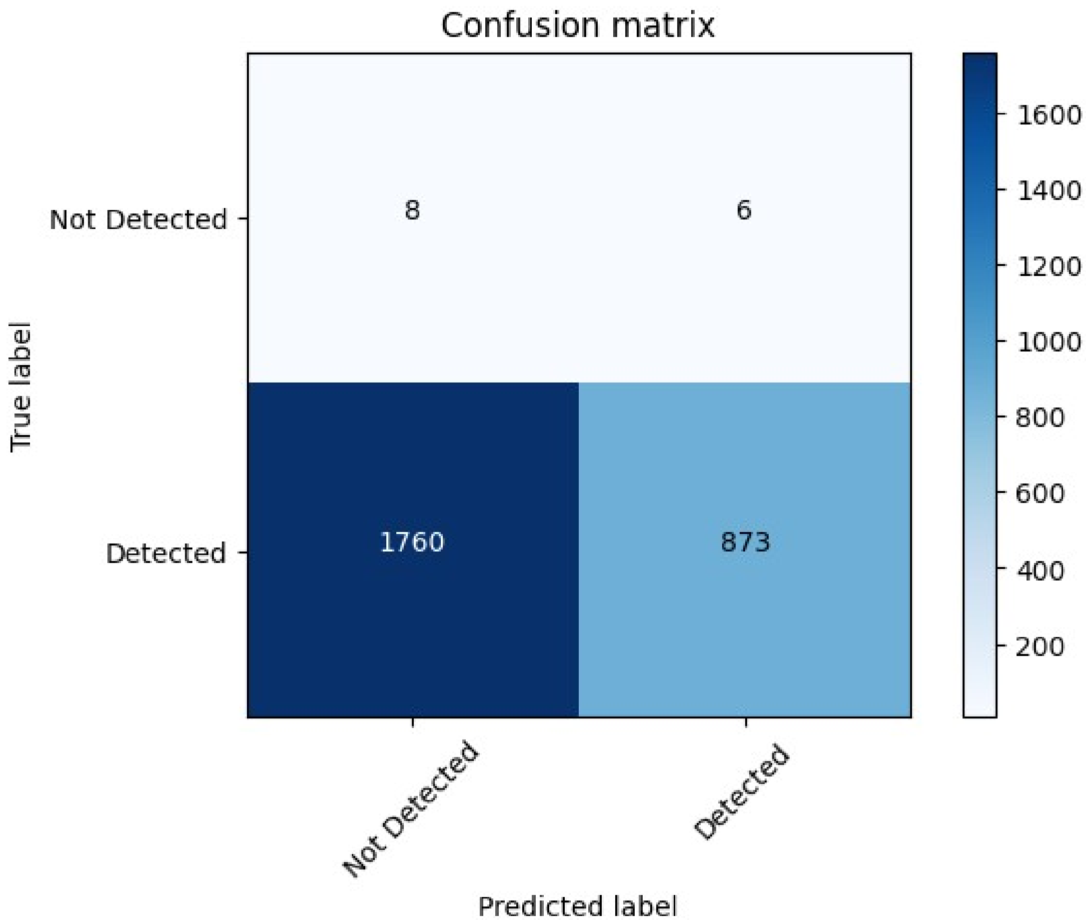
```
# Test the ablated model - normal data
# Load the test dataset
test_images = X_test_eyes # Load your test images here
test_labels = y_test_eyes # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

# Make predictions using the model
# predictions = final_model.predict(test_images)
predictions = dropout.predict(test_images)
binary_predictions = (predictions.max(axis=1) > threshold).astype(int)

# Calculate accuracy
num_correct = 0
total_images = len(test_images)

for i in range(total_images):
    predicted_class = binary_predictions[i]
    true_class = test_labels[i]
```

```
    if predicted_class == true_class:
        num_correct += 1

accuracy = num_correct / total_images
print("Face model With feature ablation, noise injection, and
selective dropout [Layers: conv3_2, conv4_2, conv5_3]:", accuracy)
```

```
83/83 [==============================] - 8s 92ms/step
Face model With feature ablation, noise injection, and selective
dropout [Layers: conv3_2, conv4_2, conv5_3]: 0.33282961843596526
```

```
# performace on normal data
y_true = test_labels
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9931740614334471
Recall: 0.33156095708317507
F1 Score: 0.4971526195899772
```



Nose

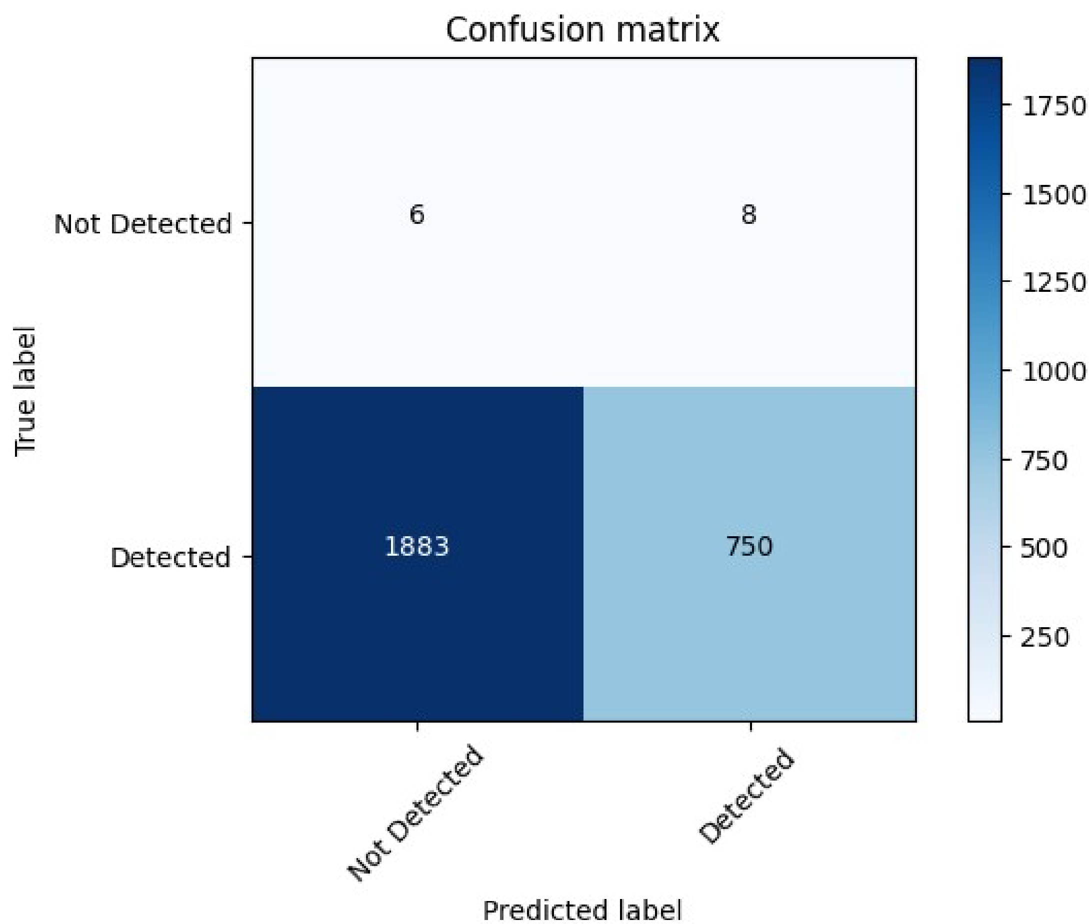
```
# Test the ablated model - normal data
# Load the test dataset
test_images = X_test_nose # Load your test images here
test_labels = y_test_nose # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

# Make predictions using the model
# predictions = final_model.predict(test_images)
predictions = dropout.predict(test_images)
binary_predictions = (predictions.max(axis=1) > threshold).astype(int)

# Calculate accuracy
num_correct = 0
total_images = len(test_images)

for i in range(total_images):
    predicted_class = binary_predictions[i]
    true_class = test_labels[i]
```

```
    if predicted_class == true_class:
        num_correct += 1

accuracy = num_correct / total_images
print("Face model With feature ablation, noise injection, and
selective dropout [Layers: conv3_2, conv4_2, conv5_3]:", accuracy)
```

```
83/83 [==============================] - 8s 92ms/step
Face model With feature ablation, noise injection, and selective
dropout [Layers: conv3_2, conv4_2, conv5_3]: 0.28560634680770686
```

```
# performace on normal data
y_true = test_labels
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9894459102902374
Recall: 0.284846183061147
F1 Score: 0.44234739015039815
```



Mouth

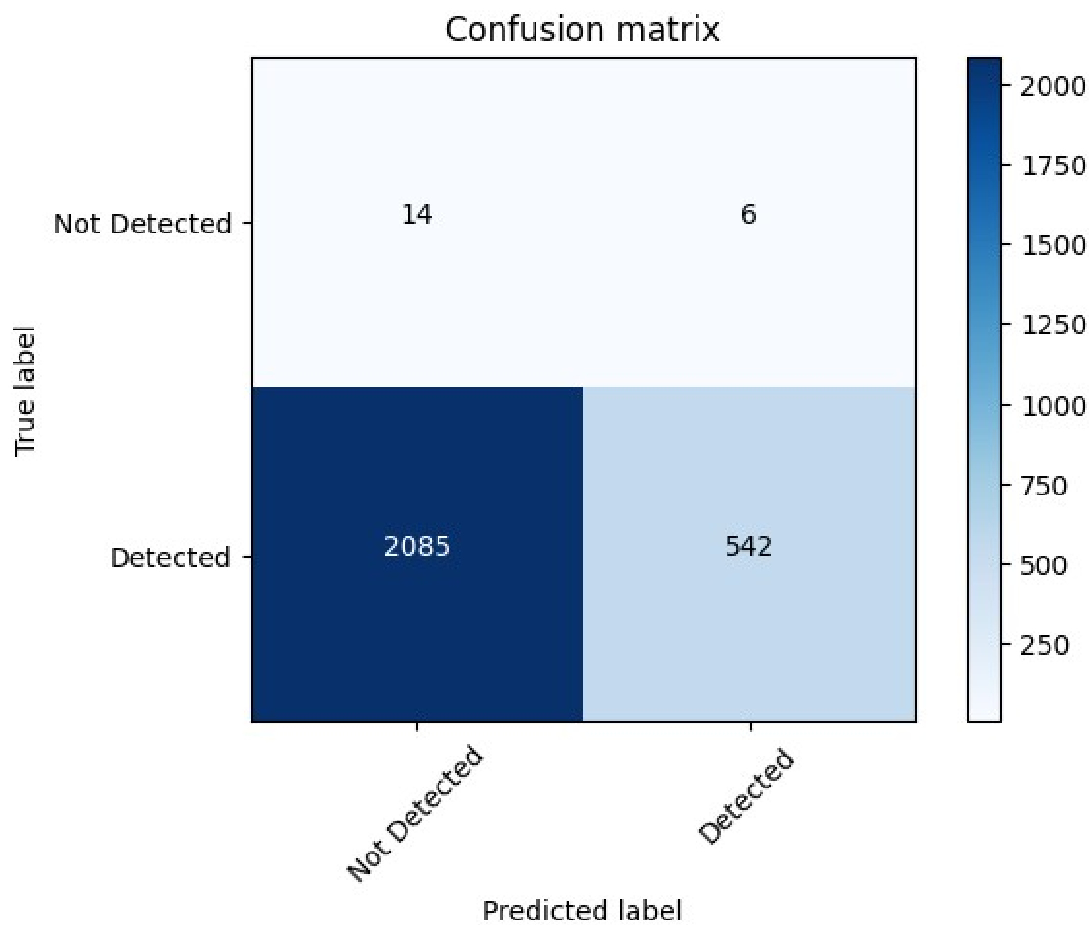
```
# Test the ablated model - normal data
# Load the test dataset
test_images = X_test_mouth # Load your test images here
test_labels = y_test_mouth # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

# Make predictions using the model
# predictions = final_model.predict(test_images)
predictions = dropout.predict(test_images)
binary_predictions = (predictions.max(axis=1) > threshold).astype(int)

# Calculate accuracy
num_correct = 0
total_images = len(test_images)

for i in range(total_images):
    predicted_class = binary_predictions[i]
    true_class = test_labels[i]
```

```
    if predicted_class == true_class:
        num_correct += 1

accuracy = num_correct / total_images
print("Face model With feature ablation, noise injection, and
selective dropout [Layers: conv3_2, conv4_2, conv5_3]:", accuracy)
```

```
83/83 [==============================] - 8s 94ms/step
Face model With feature ablation, noise injection, and selective
dropout [Layers: conv3_2, conv4_2, conv5_3]: 0.2100491122024934
```

```
# performace on normal data
y_true = test_labels
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9890510948905109
Recall: 0.20631899505138943
F1 Score: 0.34141732283464565
```



Creating Data for Neuron Manipulation

```
import cv2
import dlib
import numpy as np

# Load dlib's pre-trained face detector and landmark predictor
detector = dlib.get_frontal_face_detector()
predictor =
dlib.shape_predictor("shape_predictor_68_face_landmarks.dat")  # Make
sure to download this

# Initialize dlib's face detector (HOG-based) and load the facial
landmark predictor
detector = dlib.get_frontal_face_detector()
predictor =
dlib.shape_predictor('shape_predictor_68_face_landmarks.dat')  # Path
to the model

def get_feature_mask(image, feature_indices, scale=1.0):
```

```
    """
    Creates a mask for the specified feature by enlarging the bounding
box around the detected feature points.
    Args:
    image (numpy array): The original image.
    feature_indices (list): A list of landmark indices that define the
feature.
    scale (float): How much to scale the bounding box of the feature
for the mask.

    Returns:
    numpy array: The mask with the specified feature highlighted.
    """
    gray = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)
    faces = detector(gray, 1)

    if faces:
        face = faces[0]
        landmarks = predictor(gray, face)
        feature_coords = np.array([(landmarks.part(n).x,
landmarks.part(n).y) for n in feature_indices])
        feature_bbox = cv2.boundingRect(feature_coords)
        x, y, w, h = feature_bbox
        x_center, y_center = x + w // 2, y + h // 2
        new_width, new_height = int(w * scale), int(h * scale)
        x, y = int(x_center - new_width // 2), int(y_center -
new_height // 2)

        mask = np.zeros_like(image)
        cv2.rectangle(mask, (x, y), (x + new_width, y + new_height),
(255, 255, 255), -1)
        return mask
    else:
        # If no faces are detected, return an empty mask
        return np.zeros_like(image)

def blur_except_feature(image, feature_indices, scale=1.0):
    """
    Blurs the entire image except for the specified feature.
    """
    mask = get_feature_mask(image, feature_indices, scale)
    blurred_image = cv2.GaussianBlur(image, (21, 21), 0)
    final_image = np.where(mask == np.array([255, 255, 255]), image,
blurred_image)
    return final_image

def process_images(images, feature_indices, scale=1.0):
    # Loop over each image and process it
    processed_images = []
    for img in images:
```

```
        gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)
        processed_img = blur_except_feature(img, feature_indices, 
scale)
        processed_images.append(processed_img)
    return processed_images

# Eyebrows indices according to dlib's 68 facial landmarks
eyebrows_indices = list(range(17, 27))  # Eyebrows
# Eyes indices according to dlib's 68 facial landmarks
eyes_indices = list(range(36, 48))  # Eyes, including both the left 
and right eyes
# Nose indices according to dlib's 68 facial landmarks
nose_indices = list(range(27, 36))  # Nose
# Mouth indices according to dlib's 68 facial landmarks
mouth_indices = list(range(48, 68))  # Mouth

# Process images to create feature-specific datasets
eyebrows_images = process_images(X_val[:1], eyebrows_indices, 
scale=1.5)
eyes_images = process_images(X_val[:1], eyes_indices, scale=1.5)
nose_images = process_images(X_val[:1], nose_indices, scale=1.5)
mouth_images = process_images(X_val[:1], mouth_indices, scale=1.5)

import matplotlib.pyplot as plt

def show_images(images, title):
    plt.figure(figsize=(10, 5))
    for i, image in enumerate(images):
        plt.subplot(1, len(images), i + 1)
        plt.imshow(cv2.cvtColor(image, cv2.COLOR_BGR2RGB))
        plt.title(title)
        plt.axis('off')
    plt.show()

# Show processed images
show_images(eyebrows_images, "Eyebrows")
show_images(eyes_images, "Eyes")
show_images(nose_images, "Nose")
show_images(mouth_images, "Mouth")
```

Eyebrows

Eyes

Nose

Mouth

Functions that help us find neurons that responsible for detecting features

```
from tensorflow.keras.preprocessing.image import img_to_array,
load_img
feature_eyes = np.array([img_to_array(image) for image in
eyes_images])  # 'eyes_images' should be your dataset of images
feature_eyebrows = np.array([img_to_array(image) for image in
eyebrows_images])  # 'eyebrows_images' should be your dataset of
images
feature_nose = np.array([img_to_array(image) for image in
nose_images])  # 'nose_images' should be your dataset of images
feature_mouth = np.array([img_to_array(image) for image in
mouth_images])  # 'mouth_images' should be your dataset of images

def print_neurons_indices(neurons_indices_dict):
    for layer_name, neurons in neurons_indices_dict.items():
        print(f"Neurons in layer {layer_name} responsible for
detecting the feature:", neurons)

import numpy as np
import tensorflow as tf
from tensorflow.keras.models import Model
from tensorflow.keras.preprocessing.image import img_to_array,
load_img

def get_activations(model, layer_name, input_images):
    # Ensure input_images is 4D (batch_size, height, width, channels)
    if input_images.ndim == 3:
        input_images = np.expand_dims(input_images, axis=0)

    # Create a model that returns the outputs of the specified layer
    layer_output = model.get_layer(layer_name).output
    activation_model = Model(inputs=model.input, outputs=layer_output)

    # Predict and collect activations for the batch of images
    activations = activation_model.predict(input_images)
    return activations

def find_responsible_neurons(activations, threshold=0.75):
    # Assuming activations shape is (batch, height, width, channels)
    # Calculate the mean activation across all spatial dimensions and
the batch
    mean_activation = np.mean(activations, axis=(0, 1, 2))

    # Threshold based on a percentage of the maximum activation to
find highly activated neurons
    threshold_value = np.max(mean_activation) * threshold
    active_neurons = np.where(mean_activation >= threshold_value)[0]
```

```
    return active_neurons.tolist()

# Example usage:
# Model and layer to analyze
layer_name = 'conv1_1'

# Getting activations
activations = get_activations(face_model, layer_name, feature_eyes)

# Finding responsible neurons
responsible_neurons = find_responsible_neurons(activations)

print("Responsible Neurons:", responsible_neurons)
```

```
1/1 [==============================] - 0s 47ms/step
Responsible Neurons: [38, 46, 47, 55]
```

Custom Layer for Neuron Manipulation

```
from keras.layers import Layer
import keras.backend as K
import numpy as np

class NeuronManipulationLayer(Layer):
    def __init__(self, neuron_indices, manipulation_values, **kwargs):
        """
        A custom Keras layer to manipulate specific neurons by adding
a constant value.

        :param neuron_indices: Indices of the neurons to manipulate.
        :param manipulation_values: Values to add to the neuron
outputs. Can be positive (to activate)
                                    or negative (to inhibit).
        """
        super().__init__(**kwargs)
        self.neuron_indices = neuron_indices
        self.manipulation_values = manipulation_values
        self.manipulation_vector = None

    def build(self, input_shape):
        # The number of filters in the previous layer determines the
size of the manipulation vector
        num_filters = input_shape[-1]  # Assuming the last dimension
in the input shape is the channel/filter dimension
        manipulation_vector = np.zeros(num_filters)  # Initialize a
vector of zeros with the same size as the number of filters
        # Set the manipulation values for specified neurons
```

```
        for index, value in zip(self.neuron_indices,
self.manipulation_values):
            if index < num_filters:
                manipulation_vector[index] = value
        # Convert to a Keras variable and add as a layer weight
        self.manipulation_vector = K.variable(manipulation_vector,
name='neuron_manipulation')
        self._trainable_weights.append(self.manipulation_vector)

    def call(self, inputs, **kwargs):
        # Add the manipulation vector to the input along the last
dimension
        return inputs + self.manipulation_vector

    def get_config(self):
        config = super().get_config().copy()
        config.update({
            'neuron_indices': self.neuron_indices,
            'manipulation_values': self.manipulation_values,
        })
        return config

# Example usage in a model
from keras.models import Model

def build_model_with_manipulation(base_model, layer_name,
neuron_indices, manipulation_values):
    """
    Build a new model with neuron manipulation applied to a specific
layer.

    :param base_model: The original Keras model.
    :param layer_name: Name of the layer where neurons will be
manipulated.
    :param neuron_indices: Indices of the neurons to manipulate.
    :param manipulation_values: Values to add to the neuron outputs.
    :return: A new Keras model with neuron manipulation applied.
    """
    # Clone the base model
    cloned_model = clone_model(base_model)
    cloned_model.set_weights(base_model.get_weights())

    # Find the layer to manipulate
    manipulation_layer = None
    for layer in cloned_model.layers:
        if layer.name == layer_name:
            manipulation_layer = layer
            break

    if manipulation_layer is None:
```

```
        raise ValueError(f"Layer {layer_name} not found in the
model.")

    # Apply the manipulation after the specified layer
    x = manipulation_layer.output
    x = NeuronManipulationLayer(neuron_indices, manipulation_values)
(x)

    # Reconnect the remaining layers
    for layer in
cloned_model.layers[cloned_model.layers.index(manipulation_layer) +
1:]:
        x = layer(x)

    # Create the modified model
    model_with_manipulation = Model(inputs=cloned_model.input,
outputs=x)
    model_with_manipulation.compile(optimizer='adam',
loss='categorical_crossentropy', metrics=['accuracy'])
    return model_with_manipulation

# Define the manipulation values
manipulation_values_zero = [0.0]  # Zero value for no change

import numpy as np
from tensorflow.keras.backend import clear_session

def calculate_accuracy(test_images, test_labels, layer_name,
responsible_neurons, threshold=0.5, num_runs=5):
    """
    Evaluate the model over a number of runs and return the average
accuracy.

    :param rebuild_model_func: Function to rebuild the model.
    :param rebuild_model_args: Positional arguments for the rebuild
model function.
    :param rebuild_model_kwargs: Keyword arguments for the rebuild
model function.
    :param test_images: Array of test images.
    :param test_labels: Array of true labels for the test images.
    :param threshold: Threshold to convert predicted probabilities to
binary predictions.
    :param num_runs: Number of runs to perform.
    :return: Average accuracy over the specified number of runs.
    """
    total_accuracy = 0

    # Perform training and evaluation in a loop
    for run in range(num_runs):
```

```
        # Reset the session
        clear_session()
        face_model = build_model()
        # Rebuild the model with the provided function and arguments
        model = build_model_with_manipulation(face_model, layer_name,
responsible_neurons, manipulation_values_zero)

        # Compile the model
        # model.compile(optimizer='adam', loss='binary_crossentropy',
metrics=['accuracy'])

        # Make predictions using the model
        predictions = model.predict(test_images)

        # Convert predictions to binary using the defined threshold
        binary_predictions = (predictions >
threshold).astype(int).flatten()

        # Calculate accuracy
        num_correct = np.sum(binary_predictions == test_labels)
        accuracy = num_correct / len(test_labels)

        # Accumulate total accuracy
        total_accuracy += accuracy
        print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

    # Calculate the average accuracy over all runs
    avg_accuracy = total_accuracy / num_runs
    print(f"Average Accuracy over {num_runs} runs: {avg_accuracy *
100:.2f}%")
    return avg_accuracy, binary_predictions
```

Neuron Manipulation: Later Layer (conv5_3)

```
clear_session()
face_model = build_model()

layer_name = 'conv5_3'
activations_brows = get_activations(face_model, 'conv5_3',
feature_eyebrows)
activations_eyes = get_activations(face_model, 'conv5_3',
feature_eyes)
activations_nose = get_activations(face_model, 'conv5_3',
feature_nose)
activations_mouth = get_activations(face_model, 'conv5_3',
feature_mouth)
responsible_neurons_brows =
find_responsible_neurons(activations_brows)
responsible_neurons_eyes = find_responsible_neurons(activations_eyes)
responsible_neurons_nose = find_responsible_neurons(activations_nose)
```

```
responsible_neurons_mouth =
find_responsible_neurons(activations_mouth)
```

```
1/1 [==============================] - 0s 126ms/step
1/1 [==============================] - 0s 124ms/step
1/1 [==============================] - 0s 126ms/step
1/1 [==============================] - 0s 128ms/step
```

```
print(responsible_neurons_brows)
print(responsible_neurons_eyes)
print(responsible_neurons_nose)
print(responsible_neurons_mouth)
```

```
[21, 282]
[282]
[21, 282]
[282]
```

```
clear_session()
face_model = build_model()
brows_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_brows, manipulation_values_zero)

clear_session()
face_model = build_model()
eyes_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_eyes, manipulation_values_zero)

clear_session()
face_model = build_model()
nose_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_nose, manipulation_values_zero)

clear_session()
face_model = build_model()
mouth_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_mouth, manipulation_values_zero)
```

Eyebrows

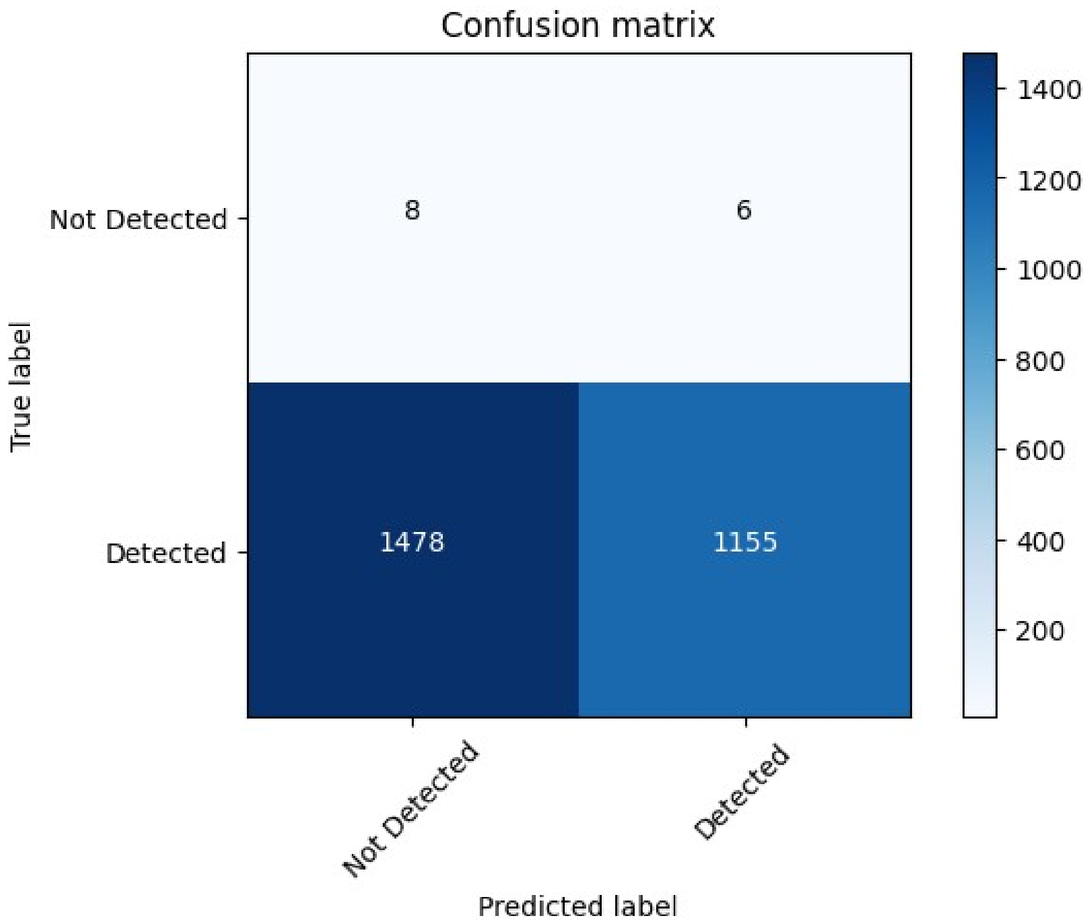
```
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

total_accuracy = 0
num_runs = 5
for run in range(num_runs):
    clear_session()
    face_model = build_model()
```

```
    brows_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_brows, manipulation_values_zero)

    predictions = brows_zero.predict(test_images)
    binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

    num_correct = np.sum(binary_predictions == test_labels)
    accuracy = num_correct / len(test_labels)

    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

avg_accuracy = total_accuracy / num_runs
print(f"[LATER LAYER] Average Accuracy over {num_runs} runs:
{avg_accuracy * 100:.2f}%")
```

```
83/83 [==============================] - 8s 96ms/step
Run 1: Accuracy = 3.17%
83/83 [==============================] - 8s 97ms/step
Run 2: Accuracy = 90.18%
83/83 [==============================] - 8s 96ms/step
Run 3: Accuracy = 95.47%
83/83 [==============================] - 8s 96ms/step
Run 4: Accuracy = 99.06%
83/83 [==============================] - 8s 96ms/step
Run 5: Accuracy = 27.77%
[LATER LAYER] Average Accuracy over 5 runs: 63.13%
```

```
# performace on normal data
y_true = y_test
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9948320413436692
Recall: 0.43866312191416634
F1 Score: 0.6088560885608857
```



Eyes

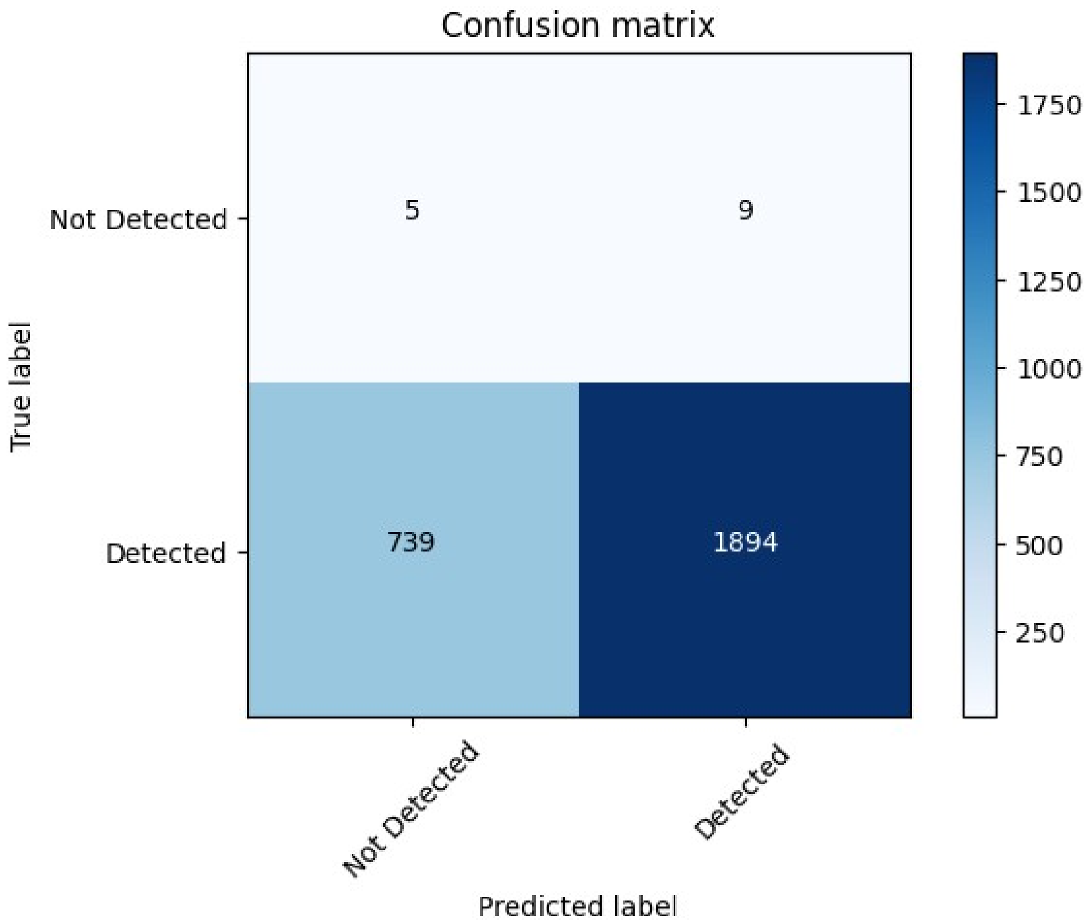
```
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

total_accuracy = 0
num_runs = 5
for run in range(num_runs):
    clear_session()
    face_model = build_model()
    eyes_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_eyes, manipulation_values_zero)

    predictions = eyes_zero.predict(test_images)
    binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

    num_correct = np.sum(binary_predictions == test_labels)
    accuracy = num_correct / len(test_labels)
```

```
    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

avg_accuracy = total_accuracy / num_runs
print(f"[LATER LAYER] Average Accuracy over {num_runs} runs:
{avg_accuracy * 100:.2f}%")
```

```
83/83 [==============================] - 8s 93ms/step
Run 1: Accuracy = 78.01%
83/83 [==============================] - 8s 93ms/step
Run 2: Accuracy = 12.01%
83/83 [==============================] - 8s 94ms/step
Run 3: Accuracy = 65.73%
83/83 [==============================] - 8s 95ms/step
Run 4: Accuracy = 1.74%
83/83 [==============================] - 8s 96ms/step
Run 5: Accuracy = 71.74%
[LATER LAYER] Average Accuracy over 5 runs: 45.85%
```

```
# performace on normal data
y_true = y_test
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9952706253284288
Recall: 0.7193315609570832
F1 Score: 0.8350970017636684
```



Nose

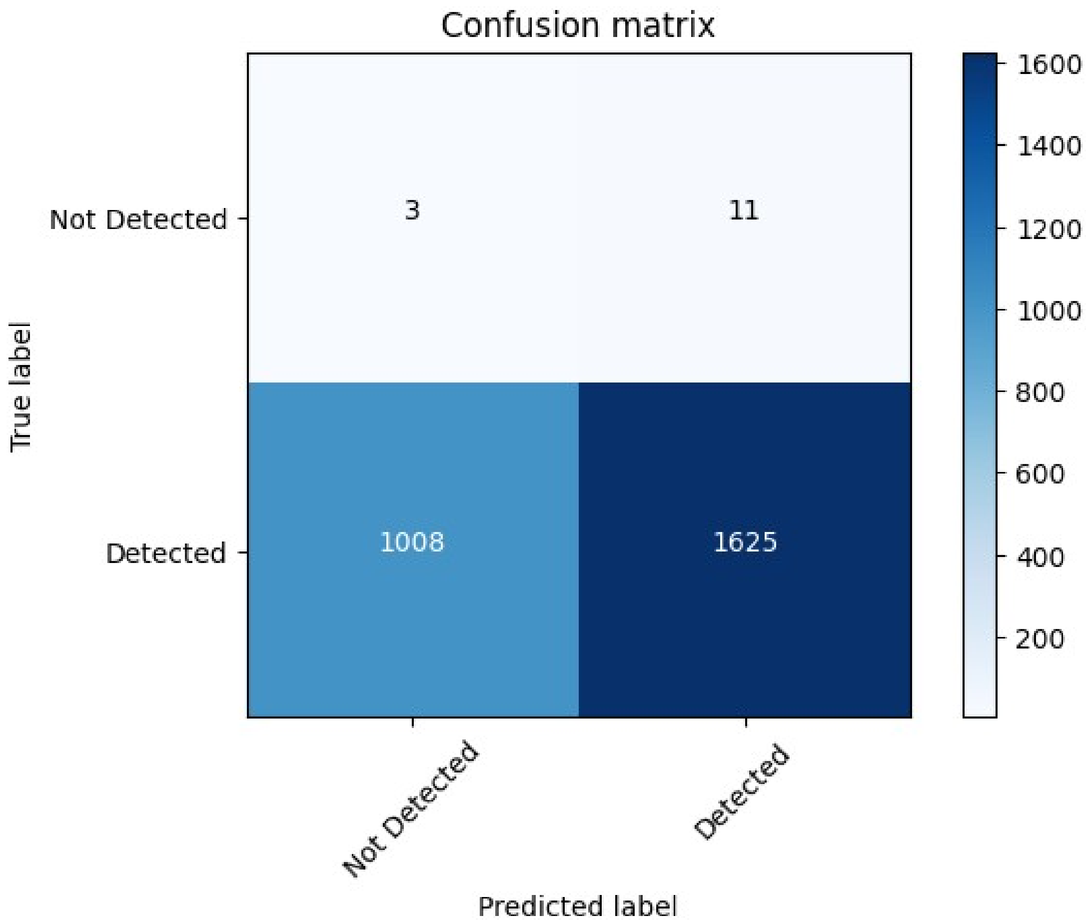
```
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

total_accuracy = 0
num_runs = 5

for run in range(num_runs):
    clear_session()
    face_model = build_model()
    nose_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_nose, manipulation_values_zero)

    predictions = nose_zero.predict(test_images)
    binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

    num_correct = np.sum(binary_predictions == test_labels)
```

```
    accuracy = num_correct / len(test_labels)

    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

avg_accuracy = total_accuracy / num_runs
print(f"[LATER LAYER] Average Accuracy over {num_runs} runs:
{avg_accuracy * 100:.2f}%")
```

```
83/83 [==============================] - 8s 96ms/step
Run 1: Accuracy = 75.07%
83/83 [==============================] - 8s 96ms/step
Run 2: Accuracy = 33.02%
83/83 [==============================] - 8s 96ms/step
Run 3: Accuracy = 3.55%
83/83 [==============================] - 8s 95ms/step
Run 4: Accuracy = 88.18%
83/83 [==============================] - 8s 95ms/step
Run 5: Accuracy = 61.50%
[LATER LAYER] Average Accuracy over 5 runs: 52.26%
```

```
# performace on normal data
y_true = y_test
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9932762836185819
Recall: 0.6171667299658185
F1 Score: 0.7613024127430311
```



Mouth

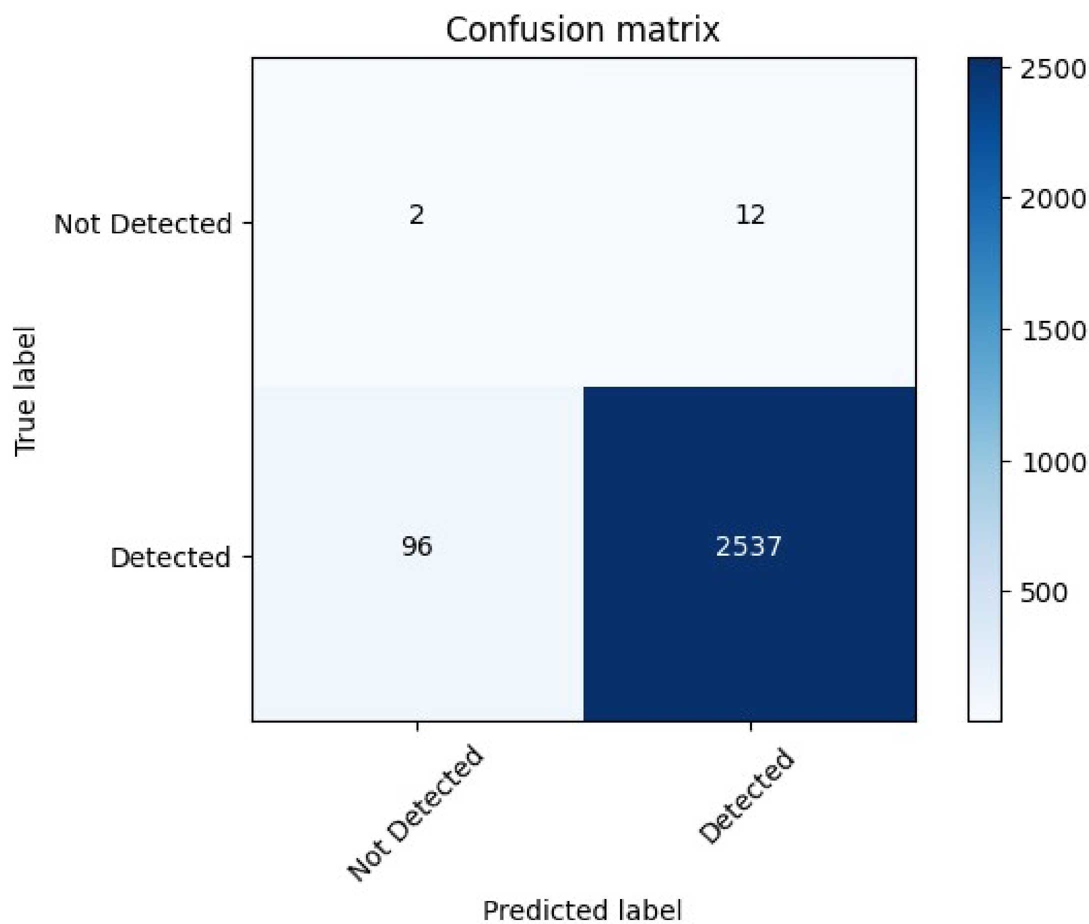
```
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

total_accuracy = 0
num_runs = 5

for run in range(num_runs):
    clear_session()
    face_model = build_model()
    mouth_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_mouth, manipulation_values_zero)

    predictions = mouth_zero.predict(test_images)
    binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

    num_correct = np.sum(binary_predictions == test_labels)
```

```
    accuracy = num_correct / len(test_labels)

    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

avg_accuracy = total_accuracy / num_runs
print(f"[LATER LAYER] Average Accuracy over {num_runs} runs:
{avg_accuracy * 100:.2f}%")
```

```
83/83 [==============================] - 8s 95ms/step
Run 1: Accuracy = 99.47%
83/83 [==============================] - 8s 95ms/step
Run 2: Accuracy = 44.77%
83/83 [==============================] - 8s 96ms/step
Run 3: Accuracy = 77.60%
83/83 [==============================] - 8s 96ms/step
Run 4: Accuracy = 36.38%
83/83 [==============================] - 8s 95ms/step
Run 5: Accuracy = 95.92%
[LATER LAYER] Average Accuracy over 5 runs: 70.83%
```

```
# performace on normal data
y_true = y_test
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9952922714790113
Recall: 0.9635396885681732
F1 Score: 0.9791586260131223
```



Neuron Manipulation: Early Layer [conv3_2]

```
clear_session()
face_model = build_model()

layer_name = 'conv3_2' # in the early layers, this layer shows the
most activation for neurons for each feature - deactivate the neurons
in this layer to simulate a deficit
activations_brows = get_activations(face_model, 'conv3_2',
feature_eyebrows)
activations_eyes = get_activations(face_model, 'conv3_2',
feature_eyes)
activations_nose = get_activations(face_model, 'conv3_2',
feature_nose)
activations_mouth = get_activations(face_model, 'conv3_2',
feature_mouth)
responsible_neurons_brows =
find_responsible_neurons(activations_brows)
responsible_neurons_eyes = find_responsible_neurons(activations_eyes)
responsible_neurons_nose = find_responsible_neurons(activations_nose)
```

```
responsible_neurons_mouth =
find_responsible_neurons(activations_mouth)
```

```
1/1 [==============================] - 0s 78ms/step
1/1 [==============================] - 0s 86ms/step
1/1 [==============================] - 0s 77ms/step
1/1 [==============================] - 0s 79ms/step
```

```
print(responsible_neurons_brows)
print(responsible_neurons_eyes)
print(responsible_neurons_nose)
print(responsible_neurons_mouth)
```

```
[2, 16, 104, 110, 142, 144, 205, 219, 225, 231, 238]
[2, 16, 104, 110, 205, 219, 225, 231, 238]
[2, 16, 104, 110, 142, 144, 205, 219, 225, 231, 238]
[2, 16, 104, 110, 142, 205, 219, 225, 231, 238]
```

```
clear_session()
face_model = build_model()
# for eyebrows
brows_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_brows, manipulation_values_zero)
```

```
clear_session()
face_model = build_model()
# for eyes
eyes_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_eyes, manipulation_values_zero)
```

```
clear_session()
face_model = build_model()
# for nose
nose_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_nose, manipulation_values_zero)
```

```
clear_session()
face_model = build_model()
# for mouth
mouth_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_mouth, manipulation_values_zero)
```

Eyebrows

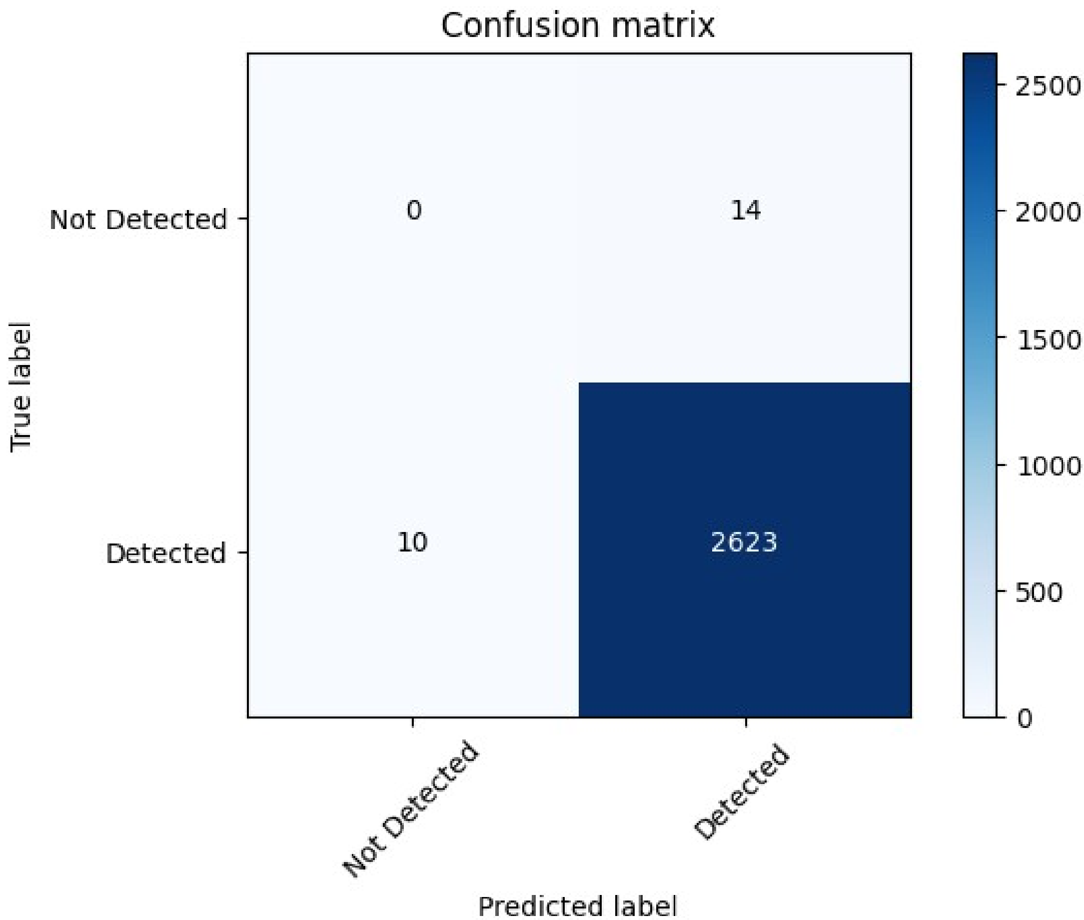
```
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

total_accuracy = 0
```

```python
num_runs = 5

for run in range(num_runs):
    clear_session()
    face_model = build_model()
    brows_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_brows, manipulation_values_zero)

    predictions = brows_zero.predict(test_images)
    binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

    num_correct = np.sum(binary_predictions == test_labels)
    accuracy = num_correct / len(test_labels)

    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

avg_accuracy = total_accuracy / num_runs
print(f"[LATER LAYER] Average Accuracy over {num_runs} runs:
{avg_accuracy * 100:.2f}%")
```

```
83/83 [==============================] - 8s 92ms/step
Run 1: Accuracy = 87.16%
83/83 [==============================] - 8s 92ms/step
Run 2: Accuracy = 74.76%
83/83 [==============================] - 8s 92ms/step
Run 3: Accuracy = 9.41%
83/83 [==============================] - 8s 92ms/step
Run 4: Accuracy = 14.28%
83/83 [==============================] - 8s 93ms/step
Run 5: Accuracy = 99.09%
[LATER LAYER] Average Accuracy over 5 runs: 56.94%
```

```python
# performace on normal data
y_true = y_test
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9946909366704588
Recall: 0.996202050892518
F1 Score: 0.9954459203036053
```



Eyes

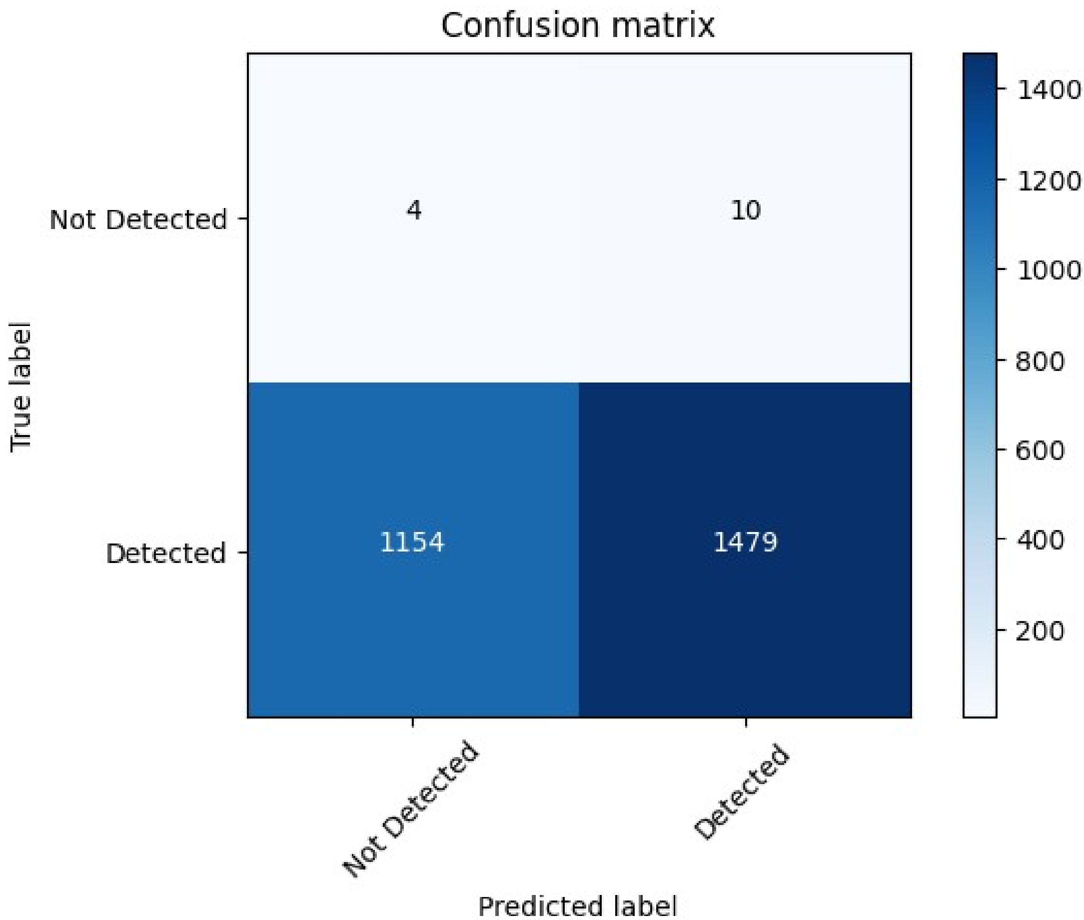
```
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

total_accuracy = 0
num_runs = 5

for run in range(num_runs):
    clear_session()
    face_model = build_model()
    eyes_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_eyes, manipulation_values_zero)

    predictions = eyes_zero.predict(test_images)
    binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

    num_correct = np.sum(binary_predictions == test_labels)
```

```
    accuracy = num_correct / len(test_labels)

    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

avg_accuracy = total_accuracy / num_runs
print(f"[LATER LAYER] Average Accuracy over {num_runs} runs:
{avg_accuracy * 100:.2f}%")
```

```
83/83 [==============================] - 8s 90ms/step
Run 1: Accuracy = 49.94%
83/83 [==============================] - 8s 90ms/step
Run 2: Accuracy = 77.30%
83/83 [==============================] - 8s 91ms/step
Run 3: Accuracy = 63.66%
83/83 [==============================] - 8s 90ms/step
Run 4: Accuracy = 40.54%
83/83 [==============================] - 8s 91ms/step
Run 5: Accuracy = 56.03%
[LATER LAYER] Average Accuracy over 5 runs: 57.49%
```

```
# performace on normal data
y_true = y_test
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9932840832773674
Recall: 0.5617166729965819
F1 Score: 0.7176128093158661
```



Nose

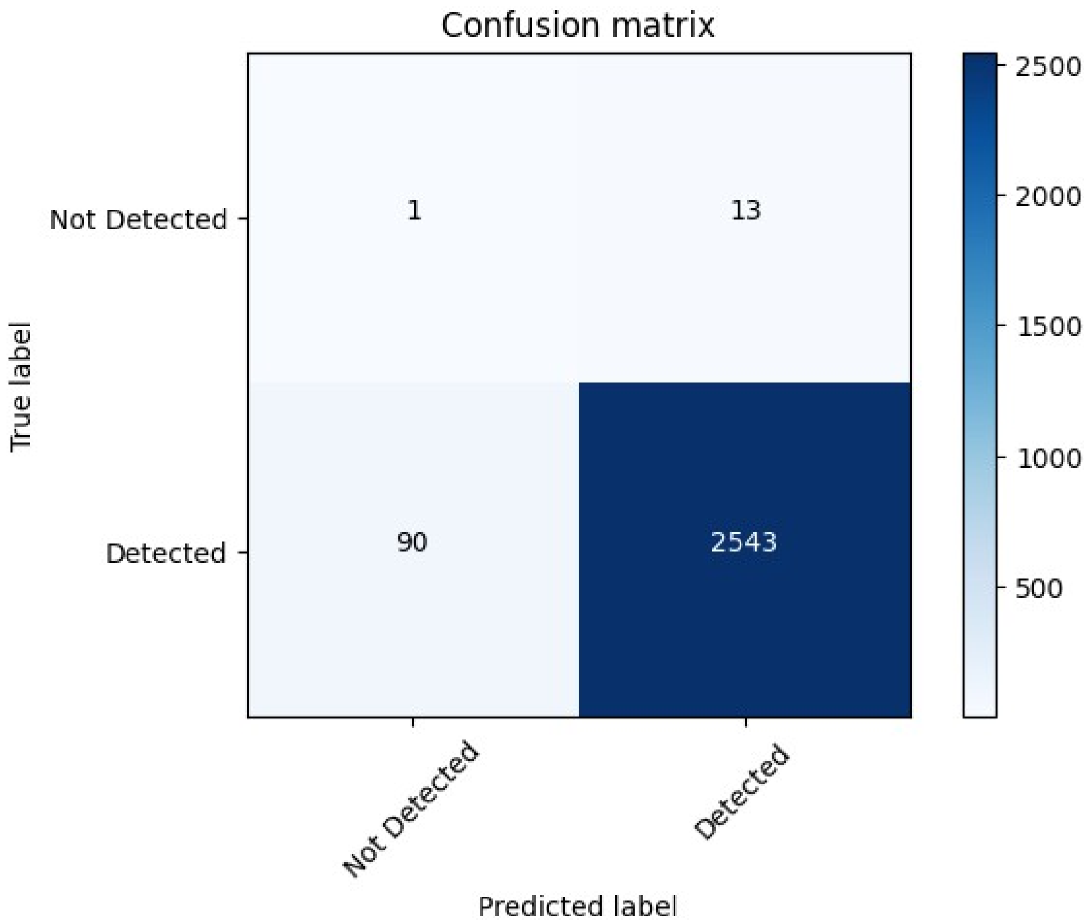
```
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

total_accuracy = 0
num_runs = 5

for run in range(num_runs):
    clear_session()
    face_model = build_model()
    nose_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_nose, manipulation_values_zero)

    predictions = nose_zero.predict(test_images)
    binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

    num_correct = np.sum(binary_predictions == test_labels)
```

```
    accuracy = num_correct / len(test_labels)

    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

avg_accuracy = total_accuracy / num_runs
print(f"[LATER LAYER] Average Accuracy over {num_runs} runs:
{avg_accuracy * 100:.2f}%")
```

```
83/83 [==============================] - 8s 90ms/step
Run 1: Accuracy = 17.15%
83/83 [==============================] - 8s 90ms/step
Run 2: Accuracy = 30.34%
83/83 [==============================] - 8s 91ms/step
Run 3: Accuracy = 90.29%
83/83 [==============================] - 8s 91ms/step
Run 4: Accuracy = 18.59%
83/83 [==============================] - 8s 92ms/step
Run 5: Accuracy = 96.11%
[LATER LAYER] Average Accuracy over 5 runs: 50.49%
```

```
# performace on normal data
y_true = y_test
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9949139280125195
Recall: 0.9658184580326623
F1 Score: 0.980150317980343
```



Mouth

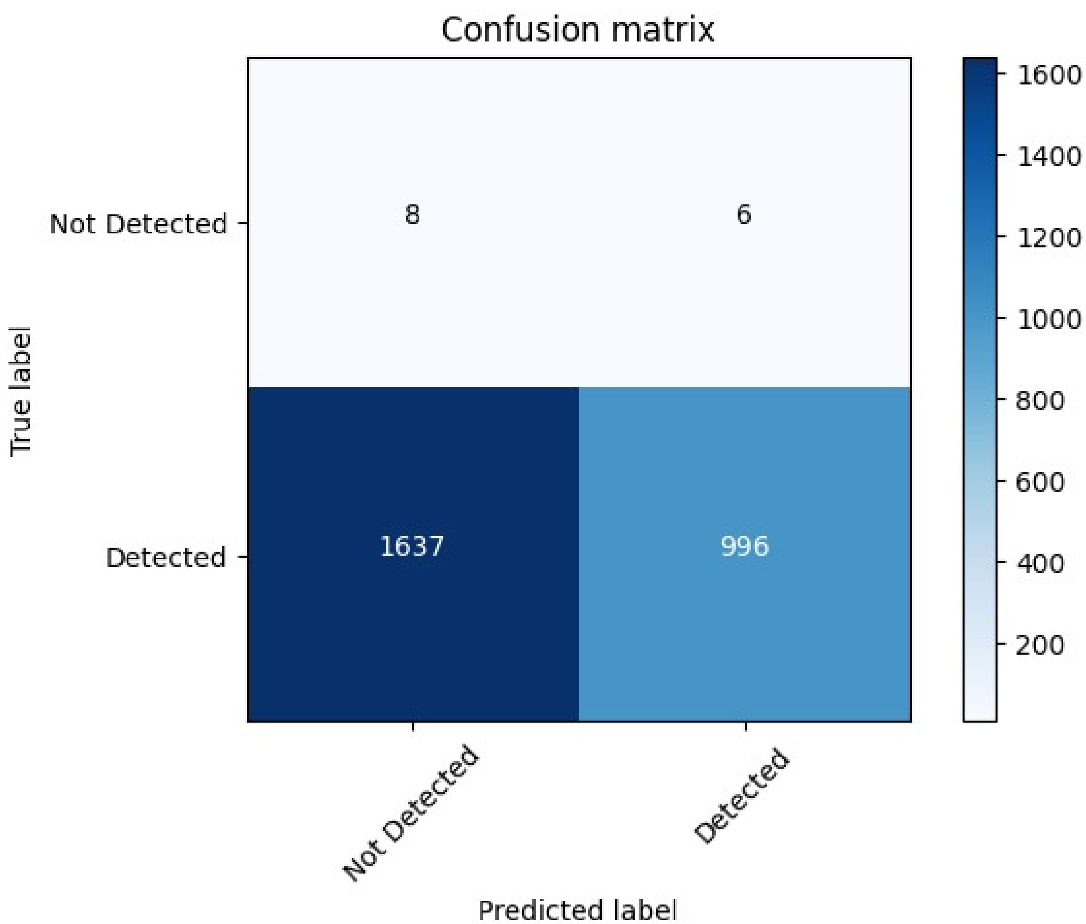
```
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

total_accuracy = 0
num_runs = 5

for run in range(num_runs):
    clear_session()
    face_model = build_model()
    mouth_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_mouth, manipulation_values_zero)

    predictions = mouth_zero.predict(test_images)
    binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

    num_correct = np.sum(binary_predictions == test_labels)
```

```
    accuracy = num_correct / len(test_labels)

    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

avg_accuracy = total_accuracy / num_runs
print(f"[LATER LAYER] Average Accuracy over {num_runs} runs:
{avg_accuracy * 100:.2f}%")
```

```
83/83 [==============================] - 8s 92ms/step
Run 1: Accuracy = 83.57%
83/83 [==============================] - 8s 92ms/step
Run 2: Accuracy = 58.90%
83/83 [==============================] - 8s 92ms/step
Run 3: Accuracy = 52.21%
83/83 [==============================] - 8s 93ms/step
Run 4: Accuracy = 0.72%
83/83 [==============================] - 8s 93ms/step
Run 5: Accuracy = 37.93%
[LATER LAYER] Average Accuracy over 5 runs: 46.66%
```

```
# performace on normal data
y_true = y_test
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9940119760479041
Recall: 0.3782757311052032
F1 Score: 0.5480055020632738
```



Neuron Manipulation: Middle Layer [conv4_2]

```
clear_session()
face_model = build_model()

layer_name = 'conv4_2' # in the early layers, this layer shows the
most activation for neurons for each feature - deactivate the neurons
in this layer to simulate a deficit
activations_brows = get_activations(face_model, layer_name ,
feature_eyebrows)
activations_eyes = get_activations(face_model, layer_name,
feature_eyes)
activations_nose = get_activations(face_model, layer_name,
feature_nose)
activations_mouth = get_activations(face_model, layer_name,
feature_mouth)
responsible_neurons_brows =
find_responsible_neurons(activations_brows)
responsible_neurons_eyes = find_responsible_neurons(activations_eyes)
responsible_neurons_nose = find_responsible_neurons(activations_nose)
```

```
responsible_neurons_mouth =
find_responsible_neurons(activations_mouth)
```

```
1/1 [==============================] - 0s 97ms/step
1/1 [==============================] - 0s 96ms/step
1/1 [==============================] - 0s 97ms/step
1/1 [==============================] - 0s 96ms/step
```

```
print(responsible_neurons_brows)
print(responsible_neurons_eyes)
print(responsible_neurons_nose)
print(responsible_neurons_mouth)
```

```
[12, 47, 170, 198, 256, 275, 479]
[12, 47, 170, 198, 256, 275, 479]
[12, 47, 170, 198, 256, 275, 479]
[12, 47, 170, 198, 256, 275, 479]
```

```
clear_session()
face_model = build_model()
brows_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_brows, manipulation_values_zero)

clear_session()
face_model = build_model()
eyes_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_eyes, manipulation_values_zero)

clear_session()
face_model = build_model()
nose_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_nose, manipulation_values_zero)

clear_session()
face_model = build_model()
mouth_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_mouth, manipulation_values_zero)
```

Eyebrows

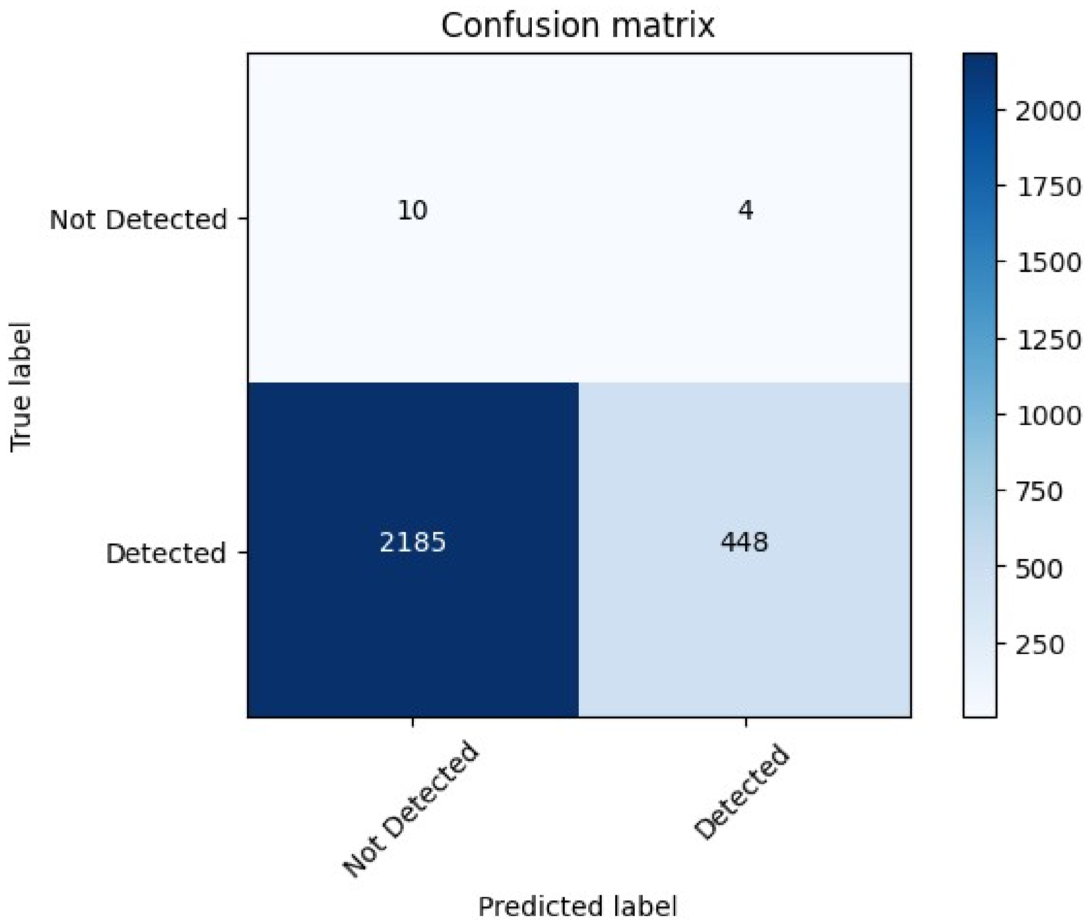
```
print(layer_name)
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

total_accuracy = 0
num_runs = 5

for run in range(num_runs):
```

```
    clear_session()
    face_model = build_model()
    brows_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_brows, manipulation_values_zero)

    predictions = brows_zero.predict(test_images)
    binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

    num_correct = np.sum(binary_predictions == test_labels)
    accuracy = num_correct / len(test_labels)

    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

avg_accuracy = total_accuracy / num_runs
print(f"[LATER LAYER] Average Accuracy over {num_runs} runs:
{avg_accuracy * 100:.2f}%")
```

```
conv4_2
83/83 [==============================] - 7s 90ms/step
Run 1: Accuracy = 96.30%
83/83 [==============================] - 8s 90ms/step
Run 2: Accuracy = 98.34%
83/83 [==============================] - 8s 90ms/step
Run 3: Accuracy = 94.33%
83/83 [==============================] - 8s 90ms/step
Run 4: Accuracy = 26.48%
83/83 [==============================] - 8s 90ms/step
Run 5: Accuracy = 17.30%
[LATER LAYER] Average Accuracy over 5 runs: 66.55%
```

```
# performace on normal data
y_true = y_test
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9911504424778761
Recall: 0.1701481200151918
F1 Score: 0.29043760129659646
```



Eyes

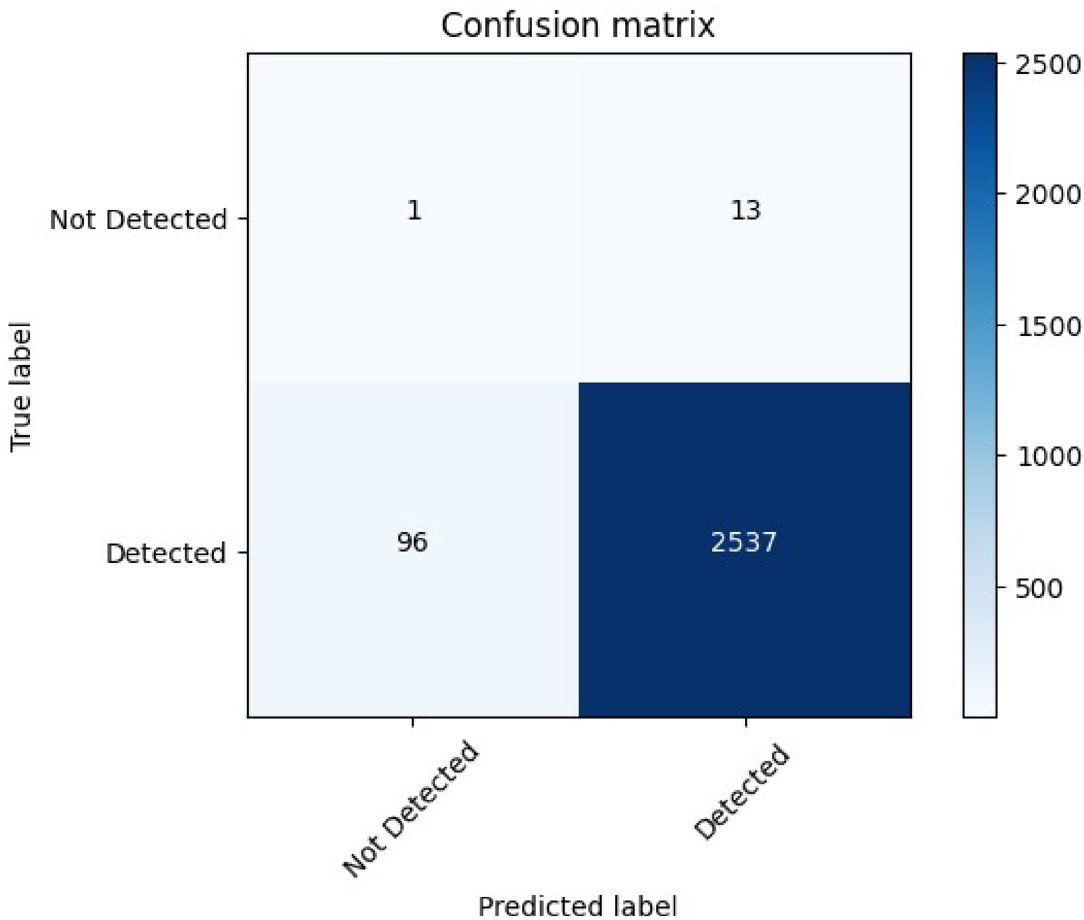
```
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

total_accuracy = 0
num_runs = 5

for run in range(num_runs):
    clear_session()
    face_model = build_model()
    eyes_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_eyes, manipulation_values_zero)

    predictions = eyes_zero.predict(test_images)
    binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

    num_correct = np.sum(binary_predictions == test_labels)
```

```
    accuracy = num_correct / len(test_labels)

    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

avg_accuracy = total_accuracy / num_runs
print(f"[LATER LAYER] Average Accuracy over {num_runs} runs:
{avg_accuracy * 100:.2f}%")
```

```
83/83 [==============================] - 8s 90ms/step
Run 1: Accuracy = 24.14%
83/83 [==============================] - 8s 90ms/step
Run 2: Accuracy = 92.41%
83/83 [==============================] - 8s 90ms/step
Run 3: Accuracy = 59.65%
83/83 [==============================] - 8s 91ms/step
Run 4: Accuracy = 20.70%
83/83 [==============================] - 8s 91ms/step
Run 5: Accuracy = 95.88%
[LATER LAYER] Average Accuracy over 5 runs: 58.56%
```

```
# performace on normal data
y_true = y_test
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9949019607843137
Recall: 0.9635396885681732
F1 Score: 0.9789697086629364
```



Nose

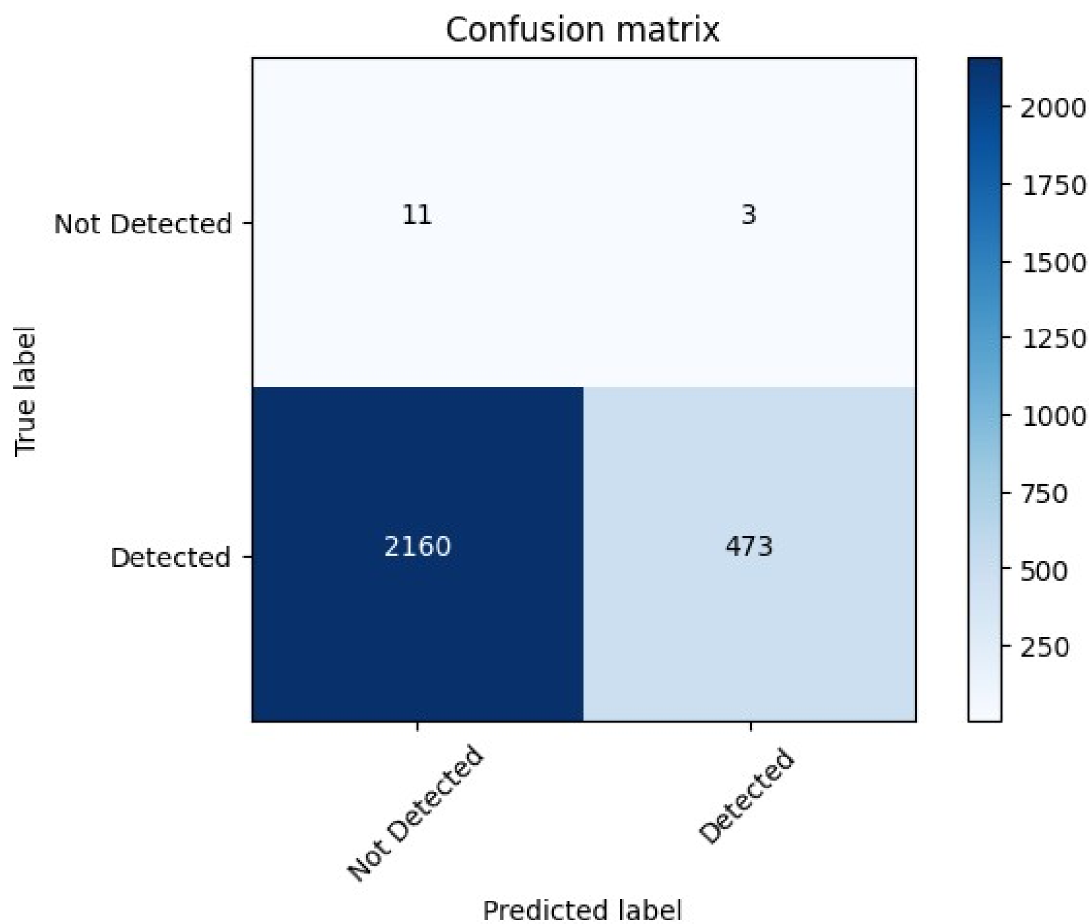
```
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

total_accuracy = 0
num_runs = 5

for run in range(num_runs):
    clear_session()
    face_model = build_model()
    nose_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_nose, manipulation_values_zero)

    predictions = nose_zero.predict(test_images)
    binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

    num_correct = np.sum(binary_predictions == test_labels)
```

```
    accuracy = num_correct / len(test_labels)

    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

avg_accuracy = total_accuracy / num_runs
print(f"[LATER LAYER] Average Accuracy over {num_runs} runs:
{avg_accuracy * 100:.2f}%")
```

```
83/83 [==============================] - 7s 90ms/step
Run 1: Accuracy = 90.18%
83/83 [==============================] - 8s 90ms/step
Run 2: Accuracy = 2.64%
83/83 [==============================] - 8s 90ms/step
Run 3: Accuracy = 2.08%
83/83 [==============================] - 8s 90ms/step
Run 4: Accuracy = 67.62%
83/83 [==============================] - 8s 90ms/step
Run 5: Accuracy = 18.28%
[LATER LAYER] Average Accuracy over 5 runs: 36.16%
```

```
# performace on normal data
y_true = y_test
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9936974789915967
Recall: 0.1796429927838967
F1 Score: 0.3042779028626568
```




```
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

# Make predictions using the model
# predictions = final_model.predict(test_images)
predictions = nose_zero.predict(test_images)
binary_predictions = (predictions.max(axis=1) > threshold).astype(int)

# Calculate accuracy
num_correct = 0
total_images = len(test_images)

for i in range(total_images):
    predicted_class = binary_predictions[i]
    true_class = test_labels[i]
    if predicted_class == true_class:
        num_correct += 1
```

```
accuracy = num_correct / total_images
print("[MIDDLE LAYER] Nose -- manipulated neurons at CONV4_2:",
accuracy)
```

```
83/83 [==============================] - 8s 95ms/step
[MIDDLE LAYER] Nose -- manipulated neurons at CONV4_2:
0.6773706082357386
```

```
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

# Make predictions using the model
# predictions = final_model.predict(test_images)
predictions = mouth_zero.predict(test_images)
binary_predictions = (predictions.max(axis=1) > threshold).astype(int)

# Calculate accuracy
num_correct = 0
total_images = len(test_images)

for i in range(total_images):
    predicted_class = binary_predictions[i]
    true_class = test_labels[i]
    if predicted_class == true_class:
        num_correct += 1

accuracy = num_correct / total_images
print("[MIDDLE LAYER] Mouth -- manipulated neurons at CONV4_2:",
accuracy)
```

```
83/83 [==============================] - 8s 96ms/step
[MIDDLE LAYER] Mouth -- manipulated neurons at CONV4_2:
0.2818284850774462
```

Mouth

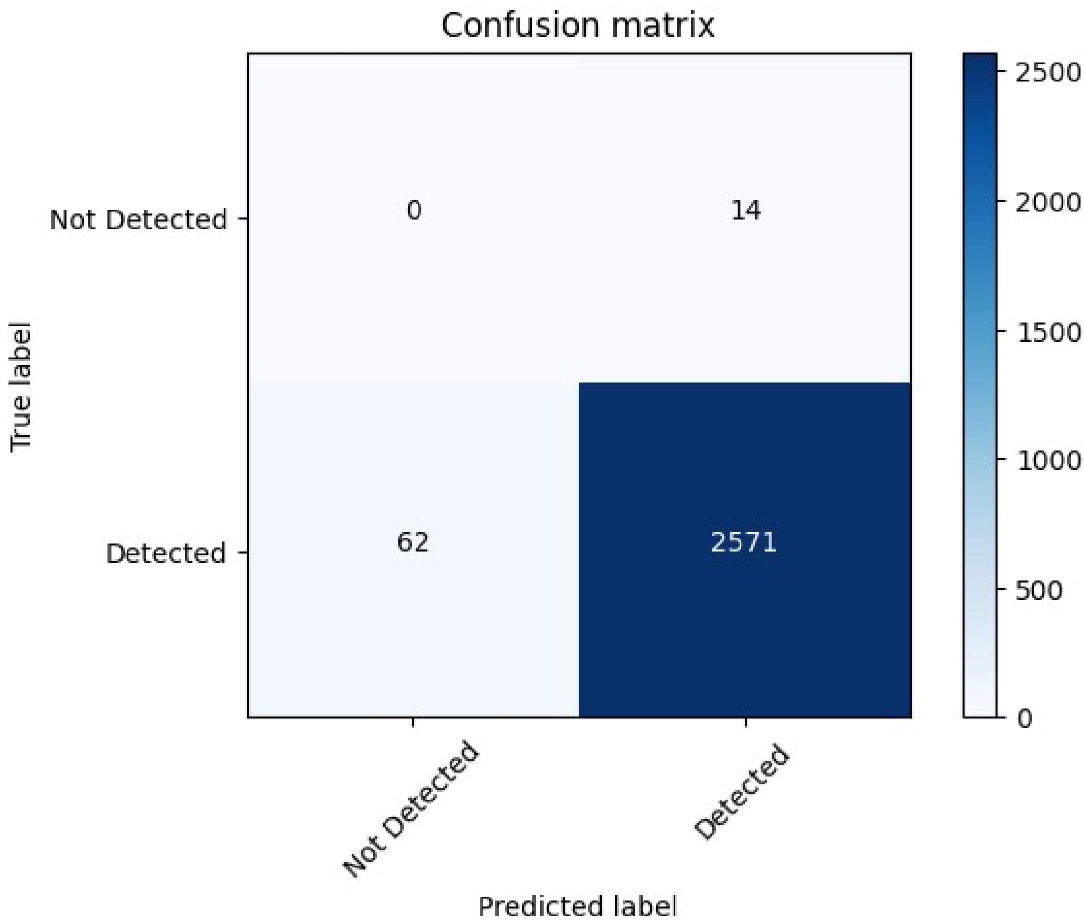
```
test_images = X_test # Load your test images here
test_labels = y_test # Load your test labels here

# Define a threshold for classifying as face detected
threshold = 0.5

total_accuracy = 0
num_runs = 5

for run in range(num_runs):
    clear_session()
    face_model = build_model()
```

```
    mouth_zero = build_model_with_manipulation(face_model, layer_name,
responsible_neurons_mouth, manipulation_values_zero)

    predictions = mouth_zero.predict(test_images)
    binary_predictions = (predictions.max(axis=1) >
threshold).astype(int)

    num_correct = np.sum(binary_predictions == test_labels)
    accuracy = num_correct / len(test_labels)

    total_accuracy += accuracy
    print(f"Run {run + 1}: Accuracy = {accuracy * 100:.2f}%")

avg_accuracy = total_accuracy / num_runs
print(f"[LATER LAYER] Average Accuracy over {num_runs} runs:
{avg_accuracy * 100:.2f}%")
```

```
83/83 [==============================] - 8s 90ms/step
Run 1: Accuracy = 40.46%
83/83 [==============================] - 8s 91ms/step
Run 2: Accuracy = 84.70%
83/83 [==============================] - 8s 91ms/step
Run 3: Accuracy = 14.96%
83/83 [==============================] - 8s 91ms/step
Run 4: Accuracy = 0.68%
83/83 [==============================] - 8s 91ms/step
Run 5: Accuracy = 97.13%
[LATER LAYER] Average Accuracy over 5 runs: 47.59%
```

```
# performace on normal data
y_true = y_test
y_pred = binary_predictions

# Calculate precision, recall, and F1 score
precision, recall, f1 = calculate_precision_recall_f1(y_true, y_pred)
print("Precision:", precision)
print("Recall:", recall)
print("F1 Score:", f1)

# Generate and plot the confusion matrix
cm = confusion_matrix(y_true, y_pred)
plot_confusion_matrix(cm)
```

```
Precision: 0.9945841392649903
Recall: 0.9764527155336119
F1 Score: 0.9854350325795324
```


Confusion matrix
Not Detected
Detected
True label
0
14
62
2571
Not Detected
Detected
Predicted label
2500
2000
1500
1000
500
0